KEPCO

BOP

BIPOLAR OPERATIONAL

POWER SUPPLY

Model BOP 36–5 (M)

Serial No. E105159

INSTRUCTION MANUAL

The KEPCO equipment described in this instruction manual is of proprietary design and is licensed under the United States patent rights of Forbro Design Corp.

The contents of this instruction manual are copyrighted. Reproduction of any part may only be made with the specific written permission of KEPCO, Inc. Data subject to change without notice.

KEPCO®

© KEPCO, Inc. 1970

KEPCO, INC. • 131-38 SANFORD AVENUE • FLUSHING, N.Y. 11352 • (212) 461-7000 • TWX # 710-582-2631 • Telex: 12-6055 • Cable: KEPCOPOWER NEWYORK

TABLE OF CONTENTS

SECTION I – INTRODUCTION

PARAGRAPH PAGE

1-1 Scope of Manual 1-1
1-3 Introduction 1-1
1-6 Description 1-1
1-12 Specifications 1-1
1-13 Specifications, Physical 1-2
1-14 Accessories 1-3

SECTION II – INSTALLATION

2-1 Unpacking and Inspection 2-1
2-3 Terminations and Controls 2-1
2-4 AC Power Requirements 2-2
2-7 Grounding 2-2
2-9 Isolation 2-2
2-11 Installation 2-2
2-13 Preliminary Electrical Check 2-2

SECTION III – OPERATION

3-1 DC Output, Local Control 3-1
3-8 Introduction to Remote Programming 3-2
3-12 External Programming Components 3-2
3-13 Preliminary Adjustments 3-2
3-16 Remote Resistance Programming 3-3
3-20 Amplifier Operation Voltage Mode 3-4
3-23 Bipolar Input with Variable Gain 3-4
3-27 Applications with Simultaneous AC/DC Output 3-5
3-31 Constant Current Output 3-7
3-34 Selection of Current Sensing Resistor 3-7
3-37 Selection of Current Control Resistor 3-7
3-39 Standard Current Regulator 3-7
3-41 Constant Current Amplifier Mode 3-8
3-44 Series Operation 3-8
3-47 Parallel Operation 3-10

SECTION IV – THEORY OF OPERATION

4-1 General 4-1
4-3 Analogy, Power Supply/Amplifier 4-1
4-7 The Ideal Amplifier 4-2
4-10 The Practical Amplifier 4-2
4-16 Gain-Frequency Characteristics 4-3
4-18 Circuit Description, General 4-4
4-20 AC Input Circuit 4-4
4-22 Main DC Supply 4-4
4-24 Series Regulator Stages 4-4
4-28 Current Limiting 4-4
4-30 Amplifier 4-5
4-35 Metering Circuit 4-5
4-37 Auxiliary Circuits 4-5

SECTION V – MAINTENANCE

5-1 General 5-1
5-3 Cover Removal 5-1
5-5 Fan Motor 5-1
5-7 Internal Adjustments 5-1
5-8 Trouble Shooting 5-1
5-10 Test Measurements 5-2

SECTION VI – ELECTRICAL PARTS LIST AND DIAGRAMS

6-1 General 6-1/6-2
6-3 Ordering Information 6-1/6-2

LIST OF ILLUSTRATIONS

FIGURE		PAGE
1-1	Typical Front View, Kepco Bipolar Operational Power Supply	-iii-
1-2	Typical Rear-View, Kepco Bipolar Operational Power Supply	-iv-
1-3	Mechanical Outline Drawing, BOP	1-4
2-1	Location of Internal Controls	2-1
2-2	Front Terminals and Controls	2-1
2-3	Rear Terminals	2-1
2-4	Main Transformer Primary Connections	2-2
2-5	Preliminary Check (Models without Suffix "M")	2-3/2-4
3-1	Load Connection, Front Panel (without Error Sensing)	3-1
3-2	Load Connection, Rear (with Error Sensing)	3-1
3-3	Load Connection, Front Panel (with Error Sensing)	3-2
3-4	Load Connection, Rear (with Error Sensing)	3-2
3-5	Test Set-Up for Offset Nulling	3-3
3-6	Programming with External Resistance	3-3
3-7	Bode'Plot for BOP	3-4
3-8	Bipolar Input with Variable Gain	3-4
3-9	Input Sources with high Internal Impedance	3-5
3-10	Current Generator as Input Source	3-5
3-11	Unipolar Output from a Bipolar Input Source	3-5
3-12	Connections for Simultaneous AC/DC Output (EX. I)	3-6
3-13	Bipolar Output from Unipolar Input Source	3-6
3-14	Connections for Simultaneous AC/DC Output (EX. II)	3-6
3-15	Current Regulator, Simplified	3-7
3-16	Standard Constant Current Regulator	3-7
3-17	Connections for Constant Current Amplifier	3-8
3-18	Series Operation into Single Load	3-9
3-19	Series Operation into Separate Loads	3-10
3-20	Parallel Operation of BOP Operational Power Supplies	3-10
4-1	BOP Operational Power Supply, Simplified Diagram	4-1
4-2	Power Supply/Amplifier Conversion	4-1
4-3	Model of Ideal Operational Amplifier	4-2
4-4	Amplifier with Input Offset Sources	4-2
4-5	Gain/Frequency (Bode') Plot, BOP	4-3
5-1	DC Test Measurements (E_{io} vs. AC Line)	5-3
5-2	DC Test Measurements (ΔI_{io} vs. AC Line)	5-4
5-3	AC Measurements, BOP	5-4
6-1	Connection Diagram	6-15
6-2	Component Location, Assembly A1	6-16
6-3	Component Location, Assembly A2	6-16
6-4	Component Location, Assembly A3	6-17/6-18
6-5	Component Location, Assemblies A4,A5	6-17/6-18
6-6	Main Schematic	6-17/6-18

LIST OF TABLES

TABLE		PAGE
1-1	AC Input/DC Output BOP Series	1-1
1-2	Specifications (Output Effects)	1-2
1-3	Specifications (Dynamic)	1-2
2-1	Internal Adjustments	2-1
2-2	Front Terminals and Controls	2-1
2-3	Rear Terminals	2-1

APPENDIX

Simplified Schematic with Rear Connection Details

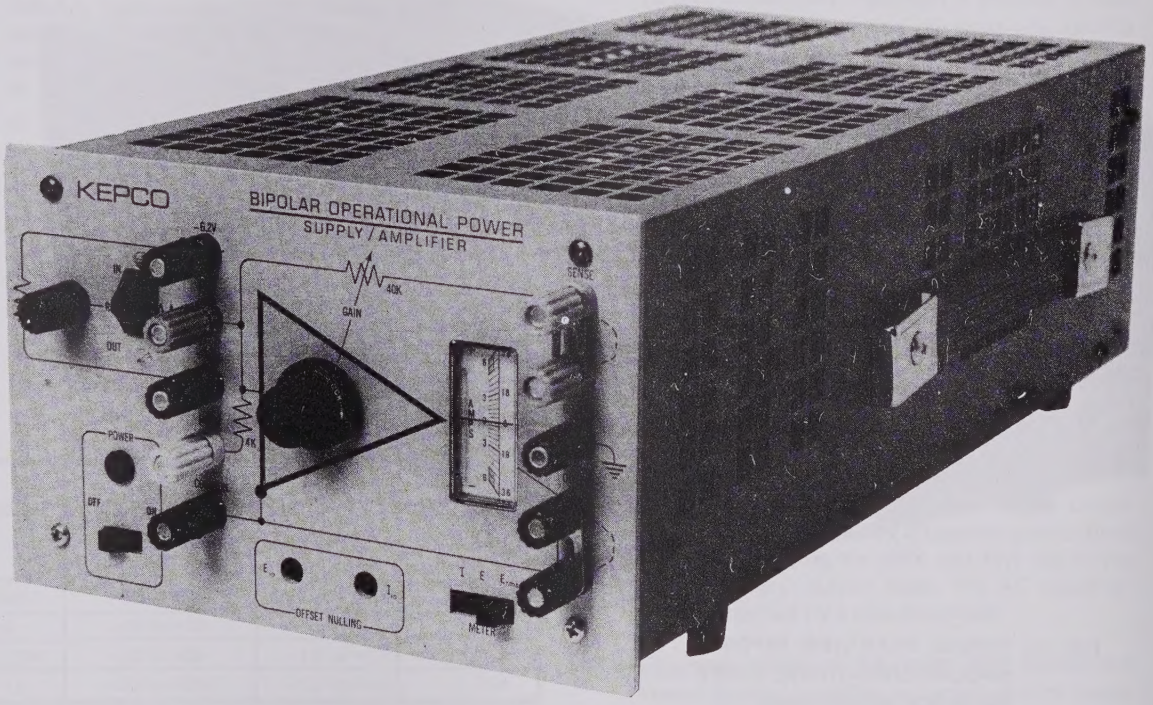


FIG. 1-1 TYPICAL FRONT VIEW, KEPCO
BIPOLAR OPERATIONAL POWER SUPPLY
(Model BOP 36–5M shown)

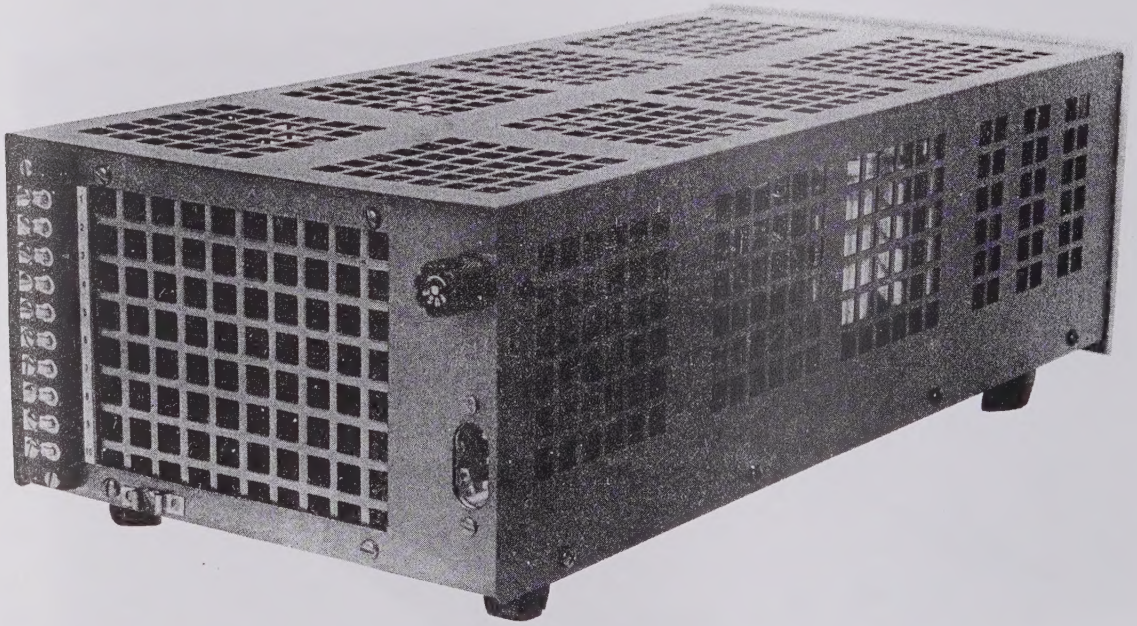


FIG. 1-2 TYPICAL REAR VIEW, KEPCO
BIPOLAR OPERATIONAL POWER SUPPLY
(Model BOP 36-5(M) shown)

SECTION I – INTRODUCTION

1-1 SCOPE OF MANUAL

1-2 This manual contains instructions for the installation, operation and maintenance of the Kepco "BOP" Series of Bipolar Operational Power Supplies.

1-3 INTRODUCTION

1-4 The Kepco "BOP" Series consists of the models listed in Table 1-1 below. All models are similar in appearance, design and specifications except as described below:

a) Output ratings are as listed in Table 1-1.

b) Models bearing the suffix "M" have operational front panels equipped with output metering, input/output binding-post terminals and built-in multi-turn rheostats for the control of gain and DC reference potential.

c) Models without suffix have a blank front panel. Access to all input/output points is provided by a rear barrier strip.

d) The rear barrier strip, the recessed offset controls and all other internal adjustments are common to all models.

MODEL	DC OUTPUT RANGE		AC INPUT CURRENT
	VOLTS	AMPS	(@125V AC)
BOP 36-5M	−36 to +36	−5 to +5	4.5A
BOP 36-5	−36 to +36	−5 to +5	4.5A
BOP 36-1.5M	−36 to +36	−1.5 to +1.5	1.75A
BOP 36 1.5	−36 to +36	−1.5 to +1.5	1.75A

TABLE 1-1 AC INPUT/DC OUTPUT, BOP SERIES

1-5 The descriptions, instructions and drawings in this manual, if not clearly identified by the specific model designation, are applicable to all BOP Bipolar Operational Power Supplies.

1-6 DESCRIPTION (Refer to FIG.'s 1-1,1-2)

1-7 The Kepco Bipolar Operational Power Supply (BOP) is a dual purpose instrument, capable of responding to AC or DC input signals of either polarity. Bipolar input and output are referred to the "common" terminal. The BOP may be represented as a DC-coupled power amplifier in the inverting configuration, delivering a NEGATIVE output for a POSITIVE input and vice versa.

1-8 The BOP is equipped with internal DC reference sources, accessible at the rear barrier strip (and on front panel binding posts on models with suffix "M") which deliver a nominal ±6.2 volts, 0–1 mA. This feature allows continuous DC output control "through zero" by means of a potentiometer connection between the two reference sources and the NULL junction (Built-in and labelled "REF" control in models with suffix "M"). The fixed parts of the amplifier offset voltage and offset current can be nulled by using the provided (recessed from the front panel) controls. Offset nulling is especially important if the BOP is used in precision programming by resistance, control voltages or currents.

1-9 An internal "MODE" switch in the BOP allows transfer of the instrument to two operating modes. In the "SLOW" mode, the BOP is unconditionally stable for any feedback (including 100%) and any load reactance. The sinusoidal full power frequency response in this operating mode is 1.8 kHz (3 dB point) with a closed loop gain of 10. In the "FAST" mode, the BOP is stable for any feedback (including 100%). Load capacitance should be restricted to 0.001 microfarad. The sinusoidal full power frequency response in this operating mode is 20 kHz (3 dB point) with a closed loop gain of 10.

1-10 The BOP is rendered completely short circuit proof by two individually adjustable current limit circuits, protecting the NPN and PNP leg of the complementary output stage. The AC input circuit is protected by a slow-blow fuse.

1-11 The main chassis of the model BOP Operational Power Supply/Amplifier is constructed of plated steel. The wrap-around cover is perforated steel, plated and painted in a dark gray texture. The front panel material is aluminum, treated and painted light gray,* (Color 26440 per Fed. Std. 595). The major part of the circuitry is located on plug-in type circuit boards for convenient access.

*Dark gray on Models without suffix "M".

1-12 SPECIFICATIONS

a) AC INPUT:
105 to 125V AC or 210 to 250V AC (selectable) 50 to 65 Hz, single phase. See Table 1-1 for AC input current.

b) DC OUTPUT RANGES:
See Table 1-1.

c) RIPPLE AND NOISE:
< 0.01% of maximum output or 3mV rms, whichever is greater.

d) OFFSET VOLTAGE AND CURRENT (E_{io},I_{io})

Zero adjustments provided, accessible from the front panel. Variations of the offset parameters (ΔE_{io},ΔI_{io}) are specified in Table 1-2.

SPECIFICATION	VOLTAGE AMPLIFIER OFFSET		6.2 V REFERENCES
	ΔE_{io}	ΔI_{io}	
LINE: 105 – 125/210 – 250 V AC	<0.1 mV	<10 nA	<0.0005%
LOAD: No Load/Full Load	<1.0 mV	<10 nA	N.A.
TIME: 8 Hours (Stability)	<0.1 mV	<50 nA	<0.005%
TEMPERATURE: Per°C (Coefficient)	<0.05 mV	<50 nA	<0.005%

TABLE 1-2 SPECIFICATIONS (OUTPUT EFFECTS)

NOTE: E_{io} is the offset voltage and I_{io} the offset current, referred to the input of the voltage comparison amplifier. Refer to Section IV (Theory of Operation) for an extensive definition and an error analysis.

e) GAIN:

1) Open Loop: >35,000 volts per volt.

2) Closed Loop: Models with suffix "M" have built-in input resistor and precision gain control, adjustable from zero to 10. With external components, closed-loop gain may be set as desired.

f) OUTPUT IMPEDANCE:

MODEL BOP 36–5 (M) . . 1.5×10^{-3} ohms
MODEL BOP 36–1.5(M) . . 5 $\times 10^{-3}$ ohms

Impedances listed are at DC, add 100 μH equivalent series inductance at higher frequencies.

g) DYNAMICS: See Table 1-3.

SPECIFICATION	MODE	BOP 36–1.5M	BOP 36–5M
SMALL SIGNAL FREQUENCY RESPONSE frequency at which the open loop gain becomes unity	FAST	300 kHz	300 kHz
	SLOW	30 kHz	30 kHz
LARGE SIGNAL FREQUENCY RESPONSE frequency at which the fully modulated, fully loaded output reaches 3% harmonic distortion	FAST	30 kHz	30 kHz
	SLOW	3 kHz	3 kHz
AMPLIFIER SLEWING RATE	FAST	7V/μsec.	7V/μsec.
	SLOW	0.7V/μsec.	0.7V/μsec.
PROGRAMMING TIME CONSTANT input/feedback set for gain=10	FAST	12 μsec.	12 μsec.
	SLOW	150 μsec.	150 μsec.
VOLTAGE RECOVERY TIME CONSTANT for step load current	FAST	50 μsec.	50 μsec.
	SLOW	500 μsec.	500 μsec.
CURRENT RECOVERY TIME CONSTANT for step load voltage	FAST	50 μsec.	50 μsec.
	SLOW	500 μsec.	500 μsec.

TABLE 1-3 DYNAMIC OUTPUT SPECIFICATIONS.

h) COOLING:

Forced air cooling by high-efficiency, long life fan.

i) REMOTE ERROR SENSING:

Special terminals (available at front panel binding posts on models so equipped) and at the rear barrier strip permit the connection of the amplifier common and the feedback resistor directly to the load, thus maintaining a low DC source resistance of the load terminals. Up to 0.5V DC voltage drop per load lead (due to load current) can be compensated for by remote sensing.

j) OVERLOAD PROTECTION:

Output is continuously protected for both polarities and in both operating modes against short circuits. Output current will limit at 5.5A [Model BOP 36–5(M)] and at 1.65A [Model BOP 36–2.5(M)].

k) AMBIENT OPERATING TEMPERATURE RANGE:

-20°C to +65°C.

l) STORAGE TEMPERATURE:

-40°C to +85°C.

m) ISOLATION VOLTAGE:

±500V (DC or AC peak) maximum, may be connected from chassis to either output terminal.

n) INTERNAL REFERENCE SUPPLIES:

Precision regulated zener sources of plus (+) and minus (-) 6.2 volts (nominal) are provided internally and terminated at the rear as well as on front panel binding posts (on models so equipped). The zener reference sources are temperature compensated and optimized for stability at a load current of 1 mA. See Table 1-2 for SPECIFICATIONS.

1-13 SPECIFICATIONS, PHYSICAL

a) METER: (Models with suffix "M" only)

Triple purpose, with selector switch.
Selectable ranges are:

1) -36 to +36V AC

2) -6 to +6A DC (Model BOP 36–5M)- -1.8A to +1.8A DC (Model BOP 36–1.5M)

3) 0 to 36V rms.

Accuracy on all scales:±5% of end value.

b) SIZE:

Refer to Mechanical Outline Drawing, FIG. 1-3. Two units may be mounted side by side in a standard size rack. For rack adapter, see ACCESSORIES, paragraph 1-14.

c) FINISH:

1) Front panel (models with suffix "M"): Light gray, Federal Standard 26440 (unless otherwise specified).

2) Front panel (models without suffix "M"): Dark gray texture.

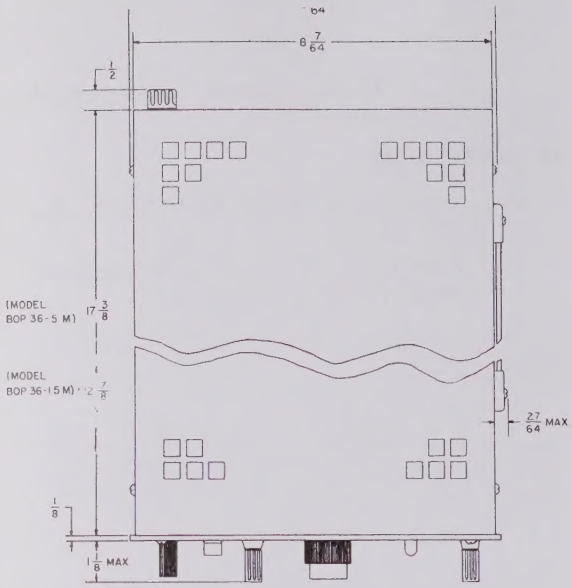
3) Case: Charcoal gray texture.

4) Chassis: Cadmium plated, cronak wash.

1-14 ACCESSORIES

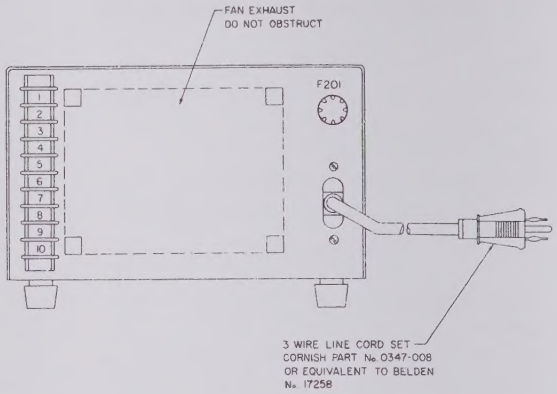
a) Rack Adapter, KEPCO Model RA 24, capacity: 2 units.

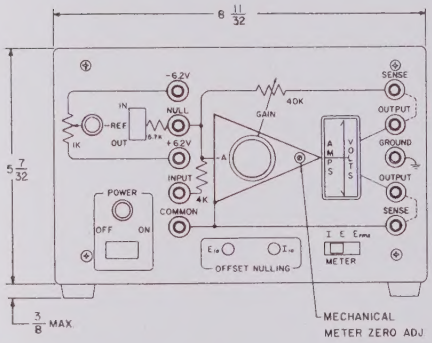
b) Filler Panel, for RA 24, to fill one empty space, KEPCO Model RFP 24–2.

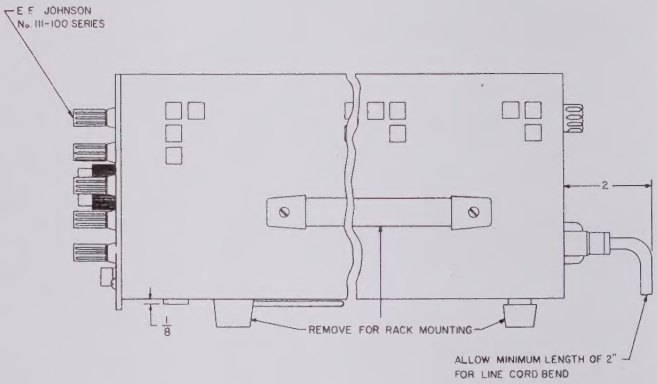


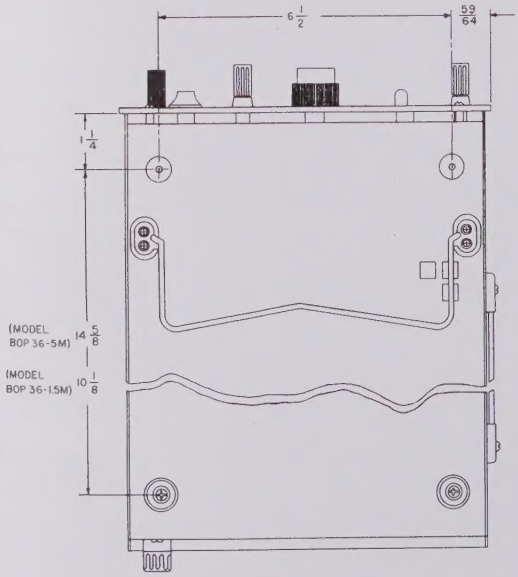
REAR OUTPUT TERMINAL FUNCTIONS

1. (+) PLUS OR (-) MINUS OUTPUT
2. SENSING (OUTPUT)
3. GROUND
4. COMMON OUTPUT
5. SENSING (COMMON)
6. (+)16.2V (WITH REFERENCE TO COMMON)
7. INPUT (4K OHMS)
8. INPUT (NULL JUNCTION
9. INPUT COMMON
10. (-)16.2V (WITH REFERENCE TO COMMON)









NOTES:

1. MATERIAL: A) COVER: # 18 GAUGE C.R.S.
   B) FRONT PANEL: 1/8 THICK ALUMINUM.
   C) CHASSIS: #14 GAUGE C.R.S.
2. FINISH: A) COVER: CHARCOAL GRAY, VINYL TEXTURE
   B) FRONT PANEL: LIGHT GRAY PER FEDERAL STD. 595, COLOR # 26440
   C) CHASSIS: CADMIUM PLATE WITH A CHROMATE WASH
3. RACK MOUNTING: REMOVE HANDLE, (4) FEET AND FRONT BAIL

FIG. 1-2 MECHANICAL OUTLINE DRAWING, BOP (METERED)

SECTION II – INSTALLATION

2-1 UNPACKING AND INSPECTION

2-2 This instrument has been thoroughly inspected and tested prior to packing. After careful unpacking, inspect for shipping damage before attempting operation. Perform the preliminary operational check as outlined in paragraph 2-13 below. If any indication of damage is found, file immediately a claim with the responsible transport service.

2-3 TERMINATIONS AND CONTROLS

a) FRONT PANEL:
Refer to FIG. 2-2 and Table 2-2.

b) REAR:
Refer to FIG. 2-3 and Table 2-3.

c) INTERNAL ADJUSTMENTS:
Refer to Table 2-1. See FIG. 2-1 for location.

REFERENCE DESIGNATION	ADJUSTMENT	PURPOSE	ADJUSTMENT PROCEDURE
R18**	AC Meter Cal.	AC meter scale calibration	par. 5-7
R35	I_O Limit (B)	Output Current Limit Adjustment	par. 5-7
R37	I_O Limit (A)	Output Current Limit Adjustment	par. 5-7
R203	E_{io} Null*	Offset voltage zero adjustment	par. 3-15
R204	I_{io} Null*	Offset voltage zero adjustment	par. 3-15
S1	Mode Switch	Slow/Fast Operating Mode	———

*The Offset Zero Adjustments (E_{io} Null, I_{io} Null) are (recessed) front panel controls
**This control provided on models with suffix "M" only.

TABLE 2-1 INTERNAL ADJUSTMENTS.

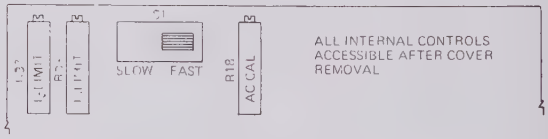


FIG. 2-1 LOCATION OF INTERNAL CONTROLS

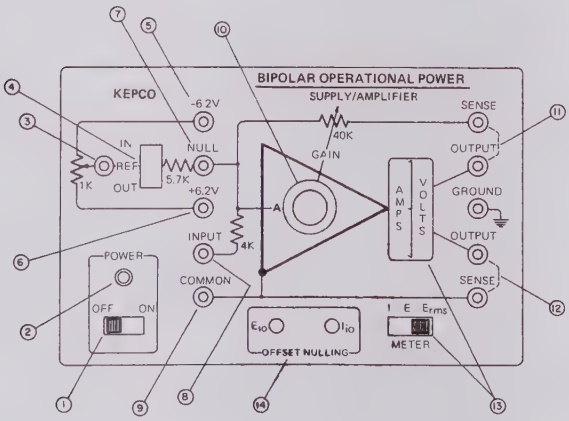


FIG. 2-2 FRONT TERMINALS AND CONTROLS

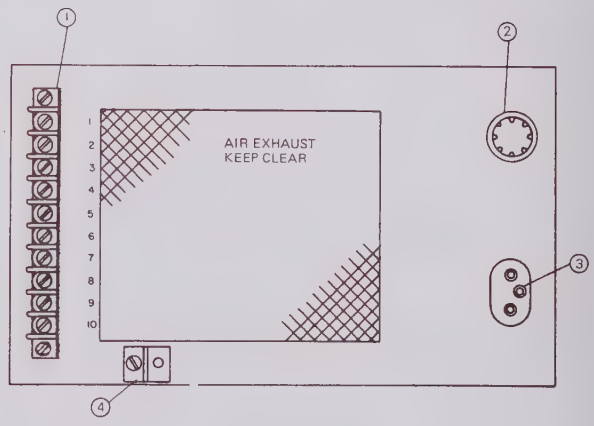


FIG. 2-3 REAR TERMINALS

NO.	DESCRIPTION OF TERMINATION
1	AC LINE POWER SWITCH
2	AC LINE POWER PILOT LIGHT
3	REFERENCE VOLTAGE CONTROL, ADJUST (–) OR (+) DC OUTPUT
4	REFERENCE SWITCH, POS. "IN" = ± DC BIAS AVAILABLE
5	MINUS (–) REFERENCE (–6.2 V NOM., REFERRED TO COMMON)
6	PLUS (+) REFERENCE (+6.2 V NOM., REFERRED TO COMMON)
7	NULL JUNCTION, INPUT TO (INVERTING) AMPLIFIER
8	INPUT FOR 0–10 GAIN WITH BUILT-IN GAIN CONTROL (R_i = 4 K ohm)
9	COMMON TERMINAL
10	PRECISION 1 TURN VOLTAGE CONTROL (POWER SUPPLY) OR GAIN CONTROL (AMP)
11	PLUS (+) OR MINUS (–) OUTPUT AND SENSING. LINKED AT FRONT OR REAR, OR CONNECTED AT THE LOAD (REMOTE SENSING)
12	COMMON OUTPUT AND SENSING. LINKED AT FRONT OR REAR, OR CONNECTED AT THE LOAD (REMOTE SENSING)
13	MULTI PURPOSE METER AND SELECTOR SWITCH, MEASURES DC OUTPUT VOLTAGE/CURRENT AND AC OUTPUT VOLTAGE
14	OFFSET NULLING CONTROLS (RECESSED SCREW DRIVER ADJUSTMENTS)

NOTE: PANELS for METERLESS MODELS (without suffix "M") ARE BLANK, EXCEPT FOR ITEM (14)

TABLE 2-2 FRONT TERMINALS AND CONTROLS

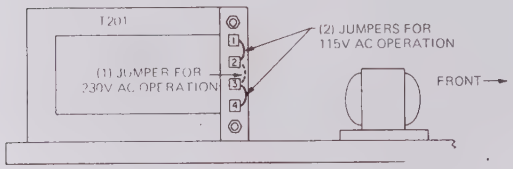
NO.	DESCRIPTION OF TERMINATION
1	REAR BARRIER STRIP (TB1), TERMINAL FUNCTIONS ARE: ① ② PLUS (+) OR MINUS (–) OUTPUT (1) AND SENSING (2) LINKED AT FRONT* OR REAR, OR CONNECTED AT THE LOAD (REMOTE SENSING) ③ CHASSIS CONNECTION, RETURN TO AC GROUND ④ ⑤ COMMON OUTPUT (4) AND SENSING (5), LINKED AT FRONT* OR CONNECTED AT THE LOAD (REMOTE SENSING) ⑥ PLUS (+) REFERENCE (+6.2 V NOM., REFERRED TO COMMON) ⑦ INPUT FOR 0–10 GAIN WITH BUILT-IN GAIN CONTROL (R_i = 4 K ohm) ⑧ NULL JUNCTION, INPUT TO (INVERTING) AMPLIFIER ⑨ INPUT COMMON, PERMANENTLY CONNECTED TO OUTPUT COMMON ⑤ ⑩ MINUS (–) REFERENCE (–6.2 V NOM., REFERRED TO COMMON)
2	AC POWER FUSE, INPUT PROTECTION
3	AC POWER INPUT JACK (CABLE SUPPLIED)
4	SPARE SHORTING LINKS (METERED MODELS ONLY)

*Models with suffix "M" only.

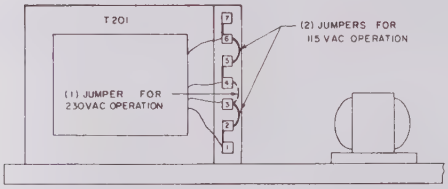
TABLE 2-3 REAR TERMINALS

2-4 AC POWER REQUIREMENT

2-5 The BOP Power Supply/Amplifier is normally delivered for operation on a single phase, 105 to 125V AC line, 50 to 65 Hz, single phase. For operation on 210 to 250V AC lines, the jumper connections on the main transformer (T201) must be changed as directed below:



a) MODELS BOP 36–1.5(M)



b) MODELS BOP 36–5(M)

FIG. 2-4 MAIN TRANSFORMER PRIMARY CONNECTIONS

2-6 PROCEDURE (Refer to FIG. 2-4)

a) Disconnect line cord from BOP.

b) Remove bare-wire jumpers between transformer terminals as shown (solid lines).

c) Connect new jumper between transformer terminals as shown (dashed lines).

d) Correct fuse values:

MODEL	115V AC	230V AC
BOP 36–5 (M)	5A–S.B.	2.5A–S.B
BOP 36 -1.5 (M)	2A–S.B.	1A–S.B

2-7 GROUNDING

WARNING

2-8 AC SAFETY GROUND. This instrument is either equipped with a three-wire safety line cord and a polarized plug (metered models, suffix "M") or a three-terminal barrier-strip for AC power input. THE POLARIZED PLUG ON THE METERED MODELS MUST BE CONNECTED TO A GROUNDED AC POWER OUTLET, AND THE GROUND TERMINAL (G) ON THE UNMETERED MODELS MUST BE RETURNED TO AC GROUND TO ASSURE OPERATOR SAFETY.

2-9 SIGNAL GROUND. The output of this instrument has no DC connection to the AC power source or the chassis. An internal signal ground is provided consisting of a resistor/capacitor combination (R1003,C1001) connected from the COMMON OUTPUT to ground. If an external signal ground is desired, the internal ground may be opened by removing the capacitor from the printed circuit board (A7, see FIG. 6-5 for location).

2-10 ISOLATION

2-11 All output and input terminals on the BOP Operational Power Supply/Amplifier are isolated from the AC power line and from the chassis. Either output terminal may therefore be grounded, or a maximum of 500 V (DC or peak to peak) may be connected between chassis and either output terminal.

***NOTE:** Input devices, connected to the "Common" of the BOP must be capable of supporting the same potential as the BOP, if the latter is operated "OFF GROUND" (Floating).

2-12 INSTALLATION

2-13 The BOP Operational Power Supply/Amplifier may be operated as a bench supply in its wrap-around case, or may be installed into any standard EIA rack. Please refer to par. 1-14 for the available mounting hardware.

2-14 PRELIMINARY ELECTRICAL CHECK

2-15 A simple electrical check-out after unpacking and before permanent installation is advisable to ascertain whether the instrument has suffered damage during shipment. Refer to FIG.'s 2-2, 2-3 and Tables 2-2, 2-3 for the identification and location of all controls and terminations. The nomenclature used will be followed throughout this manual. Controls and terminations pertaining to the BOP will be capitalized throughout the text.

a) BOP MODELS WITH SUFFIX "M."

1) POWER switch "off." Connect the BOP to 115V AC line or check paragraph 2-5 for conversion to 230V AC if desired.

2) Push Power switch to the "on" position. The red pilot light should energize. With the REF switch in the "in" position (DC Output Mode) and the REF control fully clockwise, unlock the GAIN control by turning the rear knob fully counterclockwise. This control is a high resolution vernier potentiometer acting as a "coarse/fine" adjustment. Slowly turn the GAIN control clockwise. Observe the panel meter (METER switch should be in position "E"). The output voltage should smoothly vary from zero to the maximum rated positive out-

put voltage, as the GAIN control is turned through its range.

3) Repeat check with REF control counterclockwise. Output voltage should vary from zero to its maximum rated negative value as the GAIN control is turned through the range.

4) Check meter in the "I" position of the METER switch by connecting an appropriate resistor load across the output terminals:

$(R_L = E_{max.}/I_{max.})$.

This concludes the preliminary checkout.

b) BOP MODELS WITHOUT SUFFIX "M"

1) Connect a 1 K ohm potentiometer, external metering and the load to the BOP rear barrier-strip as shown in FIG. 2-5. Disconnect R703 from A7 assembly (behind the rear barrier-strip).

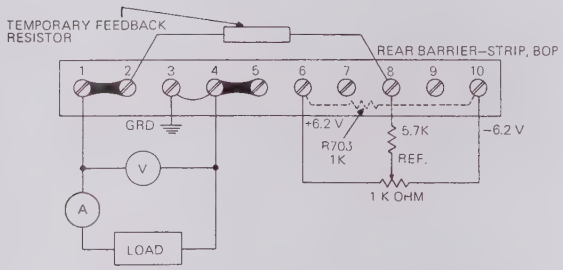


FIG. 2-5 PRELIMINARY CHECK (MODELS WITHOUT SUFFIX "M")

2) Connect BOP to 115V AC power line or check paragraph 2-5 for conversion to 230V AC if desired.

3) Observe output metering while varying the external voltage control (REF). The output should vary smoothly from the maximum rated negative output voltage through zero to the maximum rated positive output voltage, as the control is varied between its limits. Meter leads must be reversed as the BOP output changes polarity. This concludes the preliminary check-out.

4) IMPORTANT: If stability tests are to be made, the temporary feedback resistor and the Output Voltage Control must be replaced with high quality components, having Temperature Coefficients of 20 parts per million or less.

5) An alternate method of output control may be performed by connecting the 5.7 K ohm resistor directly from terminal (8) to terminal (6) for negative output or to terminal (10) for positive output with respect to common. Connect a variable feedback resistor (rheostat connected) of equal value in place of the fixed unit. This rheostat becomes now the voltage control.

NOTE: This Bipolar Operational Power Supply is equipped with a two-second time delay relay, designed to prevent immediate turn-on after the AC power is interrupted. The purpose of the delay is to permit the main filter capacitors sufficient time for discharge before the reapplication of AC power. If the turn-on should appear hesitant, or the switching "noisy," it may be due to the relay cycle, which is a normal condition. Refer to paragraph 4-40 "OVERSHOOT PROTECTION CIRCUIT" for a detailed description of the relay circuit.

SECTION III – OPERATION

3-1 DC OUTPUT, LOCAL CONTROL

3-2 GENERAL. Kepco Bipolar Operational Power Supplies (BOP) can be locally controlled either by means of built-in front panel controls (Models with suffix "M" only) or with external controls connected to the rear barrier strip (All Models). Two basic methods of locally controlling the DC output voltage have been briefly described in the previous section (see "Preliminary Electrical Check," par. 2-14). These two methods may be used separately or combined. If the REF control is set either fully clockwise or counterclockwise (by means of the internal or external potentiometer) a negative or positive control current (I_b) of approximately 1 mA is produced:

$$E_r/R_r = I_b \text{ or } 6.2\ V/5.7\ K \approx 1\ mA \qquad \text{(Eq. 1)}$$

The output voltage can now be linearly controlled by means of the built-in GAIN control (Models with suffix "M") or the externally connected feedback resistor (R_f), if the latter is changed to a rheostat. The (simplified) transfer function governing this method of control can be expressed by:

$$E_o = E_r/R_r(R_f) \qquad \text{(Eq.2)},$$

Combining equations (1) and (2) we have:

$$E_o = I_b(R_f) \qquad \text{(Eq.3) where:}$$

E_o = Output Voltage

E_r = Reference Voltage

R_f = Gain Control (Feedback Resistor)

R_r = Reference Resistor

I_b = Control Current

3-3 Referring to Eq.3, both control methods become obvious. With I_b a fixed 1 mA, the output voltage becomes a linear function of the internal or external setting of the GAIN control (R_f). Alternately if the GAIN control is left in any fixed position and the REF control is varied, the output voltage becomes a function of the control current I_b. The control current is determined by the setting of the REF control, which is connected between the (±)6.2 volt reference voltages. Since the reference resistor (R_r) is connected in series with the wiper of the REF potentiometer, the control current (I_b) can be selected between the values of (–) 1 mA and (+) 1 mA. Output voltage control from the maximum rated negative to the maximum rated positive value (continuous, through zero) is therefore possible with this method. If for example a BOP 36-5 is to be controlled as described above, the output voltage at any setting can be expressed by:

$$(\pm)\ E_o = (\pm)\ E_r[\frac{R_f}{R_r}],\ \text{or:}$$

$$(\pm)\ 36\ V \approx (\pm)\ (0 \text{ to } 6.2\ V)\ [\frac{0 \text{ to } 40K \text{ ohms}}{5.7K \text{ ohms}}]$$

3-4 While output voltage control by means of the GAIN control is linear from zero to either a negative or positive end value, (depending upon the polarity of the control current) continuous control, through zero, by means of the REF control is inherently somewhat non-linear (≈10%) due to the flow of current through the potentiometer (REF control).

3-5 LOAD CONNECTION. BOP models with functional front panels (Models with suffix "M") have the links between output and error sensing terminals connected at the front panel binding posts (See FIG. 3-1). A pair of "Spare-Links" are provided for these models at the rear (See FIG. 3-2) for the case where the load is to be connected at the rear. In the latter case, the front links must be removed and the rear links connected as shown. BOP models without functional front panel (no suffix) have the links connected at the rear as shown (See FIG. 3-2).

3-6 The load may be connected to the output terminals at the rear barrier strip or at the front panel binding posts. (See FIG.'s 3-1, 3-3, 3-4). Load wires should be of the largest practicable diameter to reduce voltage drops due to load current and to keep the output impedance as low as possible. If specified regulation directly at the load is required, remote error sensing must be used, as described below.

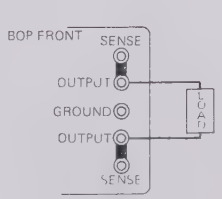


FIG. 3-1 LOAD CONNECTION, FRONT PANEL (without error sensing)

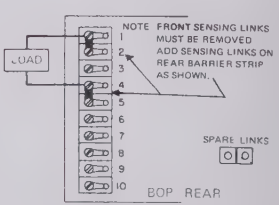


FIG. 3-2 LOAD CONNECTION REAR (without error sensing)

3-7 REMOTE ERROR SENSING. For applications requiring specified DC performance directly at the load, remote error sensing may be used to compensate for voltage drops along the load connecting wires. Up to 0.5 V per load lead can be corrected for. Error sensing may be used either from the front binding posts, or at the rear barrier strip. In the latter case, the front links between output and sensing terminals must be removed. (Refer to FIG.'s 3-3, 3-4).

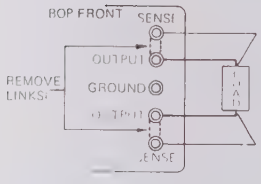


FIG. 3-3 LOAD CONNECTION, FRONT PANEL (with error sensing)

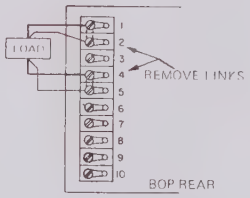


FIG. 3-4 LOAD CONNECTION, REAR (with error sensing)

3-8 INTRODUCTION TO REMOTE PROGRAMMING

3-9 GENERAL. The following paragraphs contain a sampling of possible applications of the BOP Operational Power Supply/Amplifier. The scope of this manual allows for the discussion of only a few of the almost unlimited number of operational circuits. The reader is referred to Section IV (Theory of Operation) for a short review of operational theory and to the available literature on operational amplifiers. For an extended treatment of power supply programming, please refer to the Kepco "Power Supply Handbook", available from your Kepco Representative or directly from:

KEPCO, INC.
131-38 Sanford Ave.
Flushing, New York 11352

3-10 DIAGRAMS. The operating and test set-up diagrams in this section represent ALL BOP models. The diagrams are simplified, symbolic illustrations of the BOP Operational Power Supply. Encircled, numbered terminals are rear barrier strip connections (part of ALL BOP models), while the nomenclature on all terminals coincides with the front panel labeling on those models which carry the suffix "M". The GAIN control, the REF switch, the REF control and the reference resistor (R_r = 5.7K ohm) although shown in all diagrams, are only part of the models with functional front panels (Suffix "M"). These components can be added on models without functional front panel (without suffix "M") if the applications so requires.

3-11 GROUNDING. Excessive ripple (line frequency "pick-up") at the output are often due to improper or multiple grounding (ground loop). All remote programming or amplifier systems must have a single ground point only, to which all shields, equipment cases and the COMMON input/output lead should be connected.

3-12 EXTERNAL PROGRAMMING COMPONENTS

a) RESISTORS. Resistors for external programming should be high quality, wire-wound units, with temperature coefficients of 20 parts per million or better. Their wattage rating should be at least 10 times the quiescent power dissipation. (Although the control current flowing through these resistors is normally quite low, large energy peaks may occur, when programming voltage step functions).

b) INPUT SOURCES. External programming sources should have stability specifications equal to or better than the BOP.

c) EXTERNAL SWITCHES. If step switch devices are used in resistance programming they must be of the "make before break" variety to avoid opening the feedback loop.

d) EXTERNAL LEADS. Shielded leads should be used for all external connections, except for load wires, which should be of the heaviest diameter practicable and twisted, to reduce inductance. (Excessive load-wire inductance adds to the power supply impedance and may cause deterioration of transient response). Load capacity, see band-width specifications Section I (Table 1-3).

3-13 PRELIMINARY ADJUSTMENTS

3-14 The initial offsets (E_{io} I_{io}) of the amplifier are carefully zeroed at the factory at 25°C and after 30 minute warm-up. Built in trim rheostats, accessible through front panel openings and appropiately labeled are provided for re-adjustment after component replacement or at other operating temperatures. For applications requiring high programming accuracy, the procedures described below should always be applied.

3-15 PROCEDURE, OFFSET ZEROING

a) EQUIPMENT REQUIRED

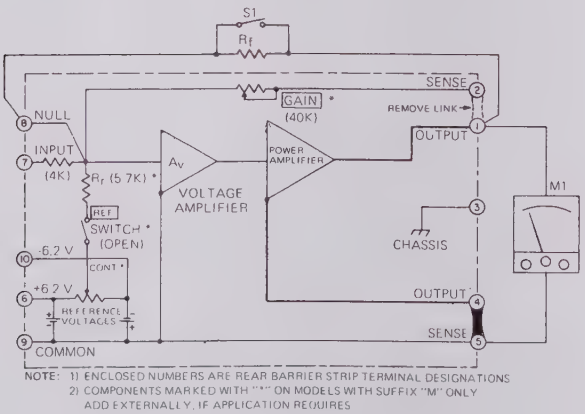
1) Sensitive Null Detector, MILLIVAC MODEL MV-07A or equivalent, or oscilloscope, TEKTRONIX MODEL 502 A (M1).
2) Switch, SPST (S1)
3) Resistance Decade Box (Megohm range) or single resistor (R_f).

b) OFFSET VOLTAGE ZERO ADJUST: (Refer to FIG. 3-5)

Close S1. Locate OFFSET VOLTAGE NULLING adjustment (marked E_{io}) at the front panel. Adjust control until null detector (M1) reads precisely zero. The adjustment may shift slightly as the BOP amplifier (and the null detector) reach thermal equilibrium. Repeat adjustment as necessary.

c) OFFSET CURRENT ZERO ADJUST: (Refer to FIG. 3-5)

Open S1. Locate OFFSET CURRENT NULLING ADJUSTMENT (marked "I_{io}") and set to exact zero as indicated on M1. Increase sensitivity of adjustment be increasing the resistance (R_f) across the feedback terminals. Repeat adjustment as necessary. With care, the offset current can be reduced to a few nanoamperes (1 nanoampere across 5 megohm represents an output voltage of 5 mV as read out on M1). Offset current nulling results in increasing input impedance (looking into the feedback terminals). This becomes important in applications where the BOP is used as an impedance transformer, since the feedback terminals represent the input of the circuit. Impedance in this case will be directly proportional to the residual effect of the offset current. With careful adjustment, Z_{in} can be raised to 10^7 - 10^8 ohms.



NOTE: 1) ENCLOSED NUMBERS ARE REAR BARRIER STRIP TERMINAL DESIGNATIONS
2) COMPONENTS MARKED WITH "*" ON MODELS WITH SUFFIX "M" ONLY ADD EXTERNALLY, IF APPLICATION REQUIRES

FIG. 3-5 TEST SETUP FOR OFFSET NULLING

3-16 REMOTE RESISTANCE PROGRAMMING

3-17 The output voltage of the BOP may be controlled remotely by means of an external feedback resistance connected between the appropriate front or rear terminals. The external feedback resistance may be fixed, continuously adjustable or step-controlled or it may be a combination of these. The high speed characteristics and specifications make the BOP especially suitable for high speed remote control, where the external feedback resistance is changed by means of relays, or solid state switching arrangements.

3-18 The value of the feedback resistance for any given output voltage is given by the transfer function

$$E_o = I_b R_f, \quad \text{where:}$$

E_o = Desired Output Voltage

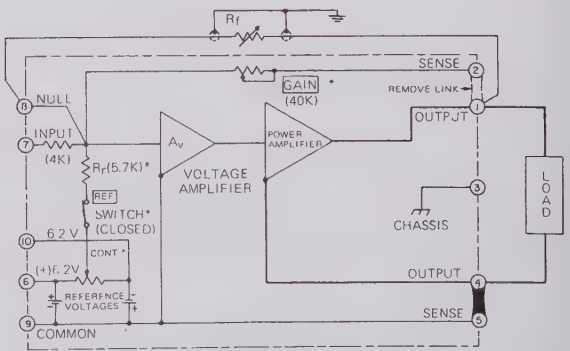
I_b = Control Current

R_f = Feedback Resistance

If the internal reference sources are used (REF switch in position "in") I_b becomes a function of the position of the REF control. I_b may be made any value between -1 mA and +1 mA, depending on the position of the REF control. If for example, we desire a zero to -30 V output swing on a Model BOP 36—5(M), the REF control would be set to -1 mA (extreme counter clockwise position) and R_f calculated by:

$E_o = I_b R_f$ or -30 V = (-1 mA) (R_f) = 30 K ohms.

Resistor tolerances may be corrected by adjusting the REF control, until a precision meter at the output shows exactly 30 volts. If on the other hand, a precision resistor with low tolerance is available for R_f, the output voltage may be adjusted with the REF control to exactly 1 mA x (R_f), thus establishing a "programming ratio" of 1000 ohm per volt, i.e. for each 1000 ohms of feedback resistance, one volt will appear at the output.



NOTE: 1) ENCLOSED NUMBERS ARE REAR BARRIER STRIP TERMINAL DESIGNATIONS.
2) COMPONENTS MARKED WITH "*" ON MODELS WITH SUFFIX "M" ONLY. ADD EXTERNALLY, IF APPLICATION REQUIRES

FIG. 3-6 PROGRAMMING WITH EXTERNAL RESISTANCE

3-19 PROCEDURE (Refer to FIG. 3-6)

a) Determine value of programming resistor (R_f) for output voltage desired.

b) Using two-wire, shielded cable, connect R_f to either front or rear terminals as shown. Connect shield to signal ground.

c) The output voltage will vary from (-1 mA) times (R_f minimum) to (-1 mA) times (R_f maximum) as the feedback resistor value is changed between its limits.

NOTE: Transfer internal bandwidth switch to the "SLOW" position if overshoot, ringing or instability (oscillation) indicate excessive phase shift of the load.

3-20 AMPLIFIER OPERATION, VOLTAGE MODE

3-21 Standard bipolar programming with the BOP Operational Power Supply/Amplifier may be performed without elaborate preparation. Once the amplifier offsets have been adjusted (See paragraph 3-13), the REF switch is transfered to position "out", (if DC biasing is not needed) and the BOP is ready for operation. Now the required operational gain can be determined and the necessary input and feedback components selected. For the calculations, we make use of the (idealized) operational amplifier equation:

$$E_o = E_i \left[\frac{R_f}{R_i}\right] \quad \text{(Eq. 2), where:}$$

E_o = Output Voltage

E_i = Input Voltage

E_i = Input Resistor

R_f = Feedback Resistor

The ratio R_i/R_f is the "closed loop" or "operational" gain of the BOP. If the provided INPUT (R_i = 4K ohm at rear terminal 7, or at the front panel if BOP is so equipped) in combination with a 40K ohm GAIN control is used (Built-in on Models with suffix "M"), the operational gain is variable from zero to 10 (R_f/R_i = 40K/4K = 10). Other gain ratios may be selected by calculating the necessary input and feedback components and, using the (direct) NULL input terminal, connecting these components externally.

3-22 Before any application, the gain/frequency properties of the BOP in the amplifier mode should be considered. An idealized graph of this characteristic (Bode plot) is shown in FIG. 3-7 below.

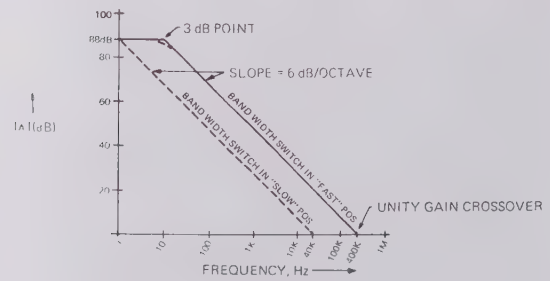


FIG. 3-7 BODE PLOT FOR BOP

Any attempt to present even a representative sample of circuit possibilities with the BOP Operational Power Supply/Amplifier must remain outside the scope of this manual. In the following paragraphs, a few examples of the versatillity of the instrument are given with the hope to stimulate the users ingenuity in designing his own circuits around the BOP. For further circuit information and applications, the user is again directed to Kepco's "Power Supply Handbook" and the standard texts on operational amplifiers.

3-23 BIPOLAR INPUT WITH VARIABLE GAIN. (Local and Remote Control)

3-24 Example I: A Model BOP 36–5(M) is to be programmed to deliver a 50 V p-p sine wave into a resistor load. The input source available is a generator with a maximum output of 5 V p-p into 600 ohms. We can expect maximum frequency response of about 20 kHz with the bandwidth switch in the "FAST" position. Using the internal GAIN control in combination with the INPUT terminal, results in a convenient output control for the amplified sine wave. (Refer to FIG. 3-8).

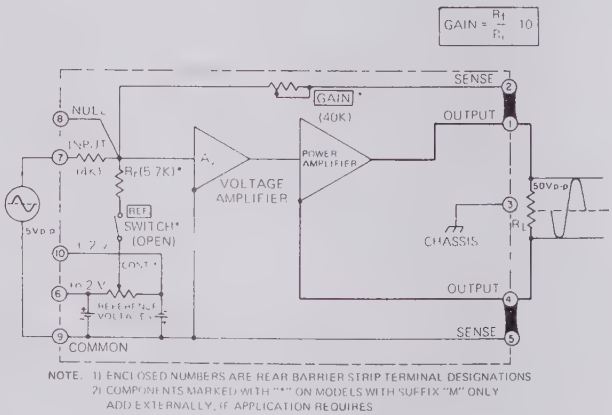


FIG. 3-8 BIPOLAR INPUT WITH VARIABLE GAIN (LOCAL CONTROL)

3-25 If other gain ratios are desired, or the instrument is to be remote controlled, the necessary input and feedback resistors may be readily calculated, utilizing equation (2):

$$E_o = E_i \left[\frac{R_f}{R_i}\right]$$

If for example the available input voltage is only 2 V p-p, we would need a gain of 25 to produce a 50 V p-p output. The value of the input resistor

(R_i) will depend upon the source impedance of E_i, if for example

R_{source} = 400 ohms,

R_i' could be chosen 600 ohm, so that

$R_{source} + R_i' = R_i$ = 1 K ohm,

then R_f would be calculated by:

$R_iG = R_f = (1\ K)\ (25) = 25\ K\ \Omega.$

Making R_f a variable resistor, will result in convenient control over the required range. (Refer to FIG. 3-9).

3-26 Other input sources, such a sawtooth or square wave voltages may be used to program the BOP if the gain/bandwidth criterium is kept in mind. If the input source has a DC component which must be blocked, the coupling capacitor must be selected large enough to pass the lowest frequency of interest or

$$C = \frac{10}{2\pi f R_i} \quad , \quad \left(X_C \leqslant \frac{R_i}{I_o} \right)$$

Where R_i is the input resistance and f is the frequency of interest (3 db point).

NOTE: If the input source has an appreciable source resistance is must be considered in all gain calculations. Although the equation for the output voltage (2) does not change, we must remember that e_i is not the open circuit output from the generator but the input voltage to the closed loop system. (FIG. 3-9).

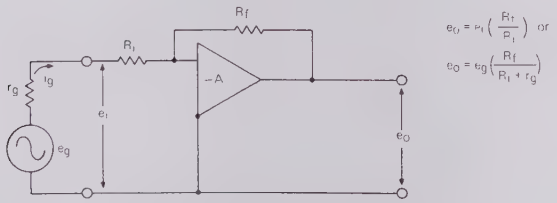


FIG. 3-9 INPUT SOURCES WITH HIGH INTERNAL IMPEDANCE

If (FIG. 3-9) e_g is the open loop generator voltage, and r_g its internal impedance, e_i may be calculated from:

$$e_i = e_g - \left[\frac{e_g}{R_i + r_g} \right] r_g, \text{ where:}$$

$e_g/R_i + r_g$

represents the control current i_g, so that e_i may also be expressed by:

$$e_i = e_g - i_g r_g.$$

We can also (analytically) convert the generator into a current source, capable of delivering a signal current i_g (see FIG. 3-10). In this case, the transfer function (Eq.2) simplifies to:

$$e_o = -i_g R_f.$$

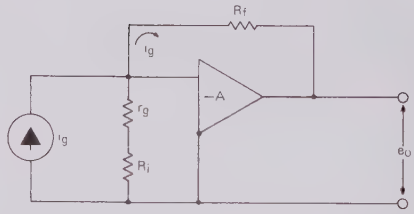


FIG. 3-10 CURRENT GENERATOR AS AN INPUT SOURCE

3-27 APPLICATIONS WITH SIMULTANEOUS AC/DC OUTPUT

3-28 There are many practical applications where it is required to add or subtract DC levels to or from the AC signal input. The BOP with its built-in bipolar DC reference sources is ideally equipped for level shifting of AC input signals.

Example I: A negative going triangular wave with an amplitude of 30 volts is desired from the output of a model BOP 36–5M. The input source is a signal generator with a peak to peak amplitude of 10 volts, transformer coupled into a 600 ohm impedance. FIG. 3-11 shows the input signal and the output desired.

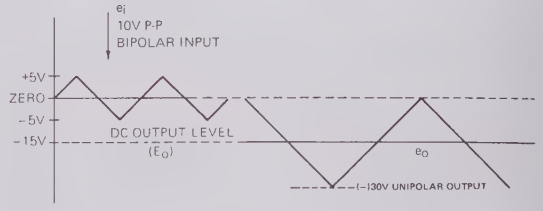


FIG. 3-11 UNIPOLAR OUTPUT FROM A BIPOLAR INPUT SOURCE

In the above example, since we want an AC output swing from zero to -30 V peak and the input source is bipolar, we must produce a DC output of -15 V, so that the amplified AC signal can swing around this axis without going positive and produce the desired output which now has, in addition to the AC signal, the desired DC level shift.

3-29 The operational equation (2) is now applied to both AC and DC conditions and both AC and DC inputs are applied to the amplifier in a summing configuration to obtain the desired results.

a) DC CONDITIONS:

$$E_O = -E_i \left[\frac{R_f}{R_i}\right] \quad \text{(Eq.2)}$$

E_O desired: −15V

Since the reference voltage (E_i = -6.2V) is available, the GAIN control (internal or external) is adjusted to 40K ohms and the REF control (internal or external) such that the DC output is equal to -15 volts. This adjustment establishes the necessary DC bias level.

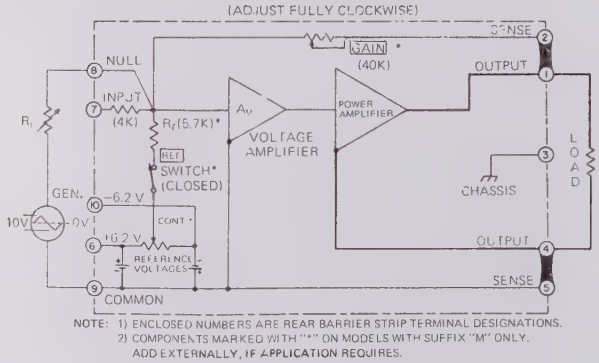
b) AC CONDITIONS:

$e_O = e_i\,(R_f/R_i)$;

e_O desired = 30V p−p

e_i max. = 10V p−p

The required gain (R_f/R_i) is therefore 3. Since the built-in feedback control (R_f = 40 K ohms) is used, the input resistance must be: $R_i = R_f/3$ or 13.3 K ohm. If an amplitude control on the input source is available, R_i may be chosen somewhat smaller and the proper signal amplitude can be adjusted on the generator. Alternately R_i may be made adjustable in order to obtain the correct signal input. The DC zero level may be corrected by adjusting the REF control on the front panel of the BOP. The necessary external connections to the BOP as shown in FIG. 3-12 below.



NOTE: 1) ENCLOSED NUMBERS ARE REAR BARRIER STRIP TERMINAL DESIGNATIONS.
2) COMPONENTS MARKED WITH "*" ON MODELS WITH SUFFIX "M" ONLY. ADD EXTERNALLY, IF APPLICATION REQUIRES.

FIG. 3-12 CONNECTIONS FOR SIMULTANEOUS AC/DC OUTPUT (EX.I)

3-30 Similar circuits with similar external connections as the example given (FIG. 3-12) may be constructed for a great variety of applications. If for instance a positive going output is required (instead of the previous negative output) under otherwise identical conditions, the DC output need only to be adjusted (by means of the REF control) to (+) 15 V. Unipolar signal sources (positive or negative) may be used with equal ease, an example is given below:

Example II: A bipolar, 70 V p-p square wave output is desired from a model BOP 36–5M. The input source is a positive going square wave generator with a peak amplitude of 1 volt and with 1 K ohm source resistance.

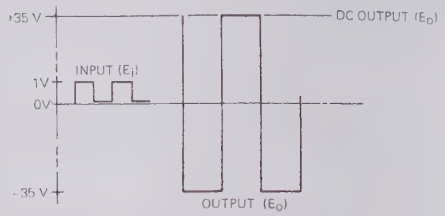


FIG. 3-13 BIPOLAR OUTPUT FROM UNIPOLAR INPUT SOURCE

As seen from FIG. 3-13, for this input a "pre-biasing" of the DC output to +35 V is needed, along with an AC gain of 70 in order to produce the desired AC voltage swing. We proceed as before:

a) DC CONDITIONS
With the GAIN control fully clockwise, adjust the output to (+) 35 V by means of the REF control.

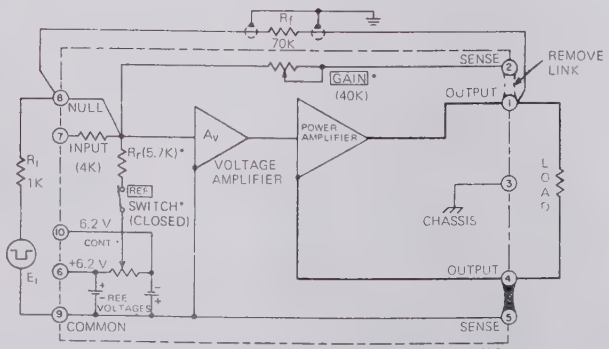
b) AC CONDITIONS

e_O = 70V p−p

e_i = 1V p−p

$\therefore$ gain needed: $\frac{R_f}{R_i} = 70$

Since with the built-in gain control R_f is given with 40 K, R_i must be 40 K/70≈570 ohms. Since the source resistance of our generator is 1 K ohm however, we find the internal gain control can not be used in this case. Instead, since R_f/R_i = 70, R_f must be 70 K ohms and is connected externally. The components are now connected externally as shown, in FIG. 3-14, the DC output re-adjusted with the REF control and programming can commence.



NOTE: 1) ENCLOSED NUMBERS ARE REAR BARRIER STRIP TERMINAL DESIGNATIONS
2) COMPONENTS MARKED WITH "*" ON MODELS WITH SUFFIX "M" ONLY. ADD EXTERNALLY, IF APPLICATION REQUIRES

FIG. 3-14 CONNECTIONS FOR SIMULTANEOUS AC/DC OUTPUT (EX.II)

3-31 CONSTANT CURRENT OUTPUT

3-32 The BOP Operational Power Supply, operated as a constant current power supply or amplifier, comes as close to an ideal current source as the state of the art permits. Due to its low output capacitance the BOP exhibits excellent current recovery properties for rapidly changing load. Its recovery time for a voltage step function is directly related to its specified slewing rate*. The recovery time is specified in μ sec./volts, since the characteristics of a current regulator is such that its output voltage (compliance) changes proportionally to the load resistance, thus maintaining the load current constant. The speed with which this takes place is then a measure of recovery characteristic of the regulator. A comparison with a standard power supply (recovery time typically 2 m sec./volt makes the current recovery time of the BOP even more impressive.

3-33 To operate the BOP in the constant current mode, an external current sensing resistor is added. This resistor (R_S) yields a voltage drop, proportional to the output current. The voltage drop (V_S) is now held constant in reference to either the internal DC reference, or to an input signal. In effect therefore, the main difference between voltage and current mode operation is that in the former the voltage across the load is regulated, and in the latter, the voltage across R_S.

3-34 SELECTION OF THE CURRENT SENSING RESISTOR

3-35 R_S must be chosen with care. The high gain amplifier connected across it will indiscriminately respond to all changes produced. Variations not due to load current changes, such as those produced by noise and temperature rise, must therefore be kept as low as possible. The current sensing resistor should consequently be a wire-wound, high quality unit with a temperature coefficient as low as possible and a wattage rating of at least ten times the actual power dissipated. In addition, it should have the configuration of a four-terminal network. (Tepro-TM series or equivalent).

3-36 The value of R_S is chosen on the basis of a one volt sample at the maximum output current desired: $R_S = 1\ V/I_{O(max.)}$ where I_O is the output current. The absolute value of R_S is not critical and can be the nearest standard resistance available since I_O can be readily adjusted. The sample voltage (V_S) should not be chosen to high however, since the detrimental effects of higher power dissipation must be avoided. On the other hand, with a too low value of V_S, the signal to noise ratio becomes a problem. The suggested one volt represents therefore a practical compromise for a large number of applications. If a large range of output current must be regulated, several sensing resistors must be used selectively to achieve optimum performance.

***NOTE:** See Section I, (Table 1-3).

3-37 SELECTION OF THE CURRENT CONTROL RESISTOR

3-38 If the internal references in the BOP are used, current control is available by means of the REF control, and a fixed "coupling" resistor (R_C) may be used to complete the closed loop circuit. Since a non-linear control is not always desirable however, the coupling resistor may be made variable and the REF control left at a fixed value, thus providing linear current control. Actual values may be calculated by referring to the simplified circuit shown in FIG. 3-15.

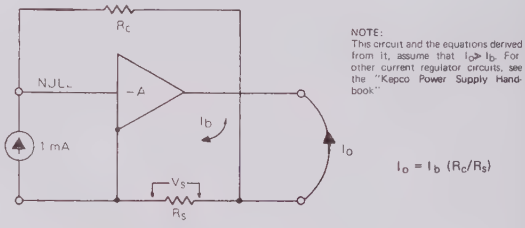


FIG. 3-15 CURRENT REGULATOR, SIMPLIFIED

The internal reference source delivers 1 mA to the null junction. At balance, 1 mA control current must flow so that: $I_bR_C = I_OR_S$. If therefore R_S was selected to drop 1 volt at a certain I_O, R_C must be 1000 ohms, since we selected a control current (I_b) of 1 mA. Practical component selection will be demonstrated by means of examples below.

3-39 STANDARD CONSTANT CURRENT REGULATOR

3-40 FIG. 3-16 shows the BOP Operational Power Supply/Amplifier connected as a continuously variable, DC constant current power supply with reversible polarity.

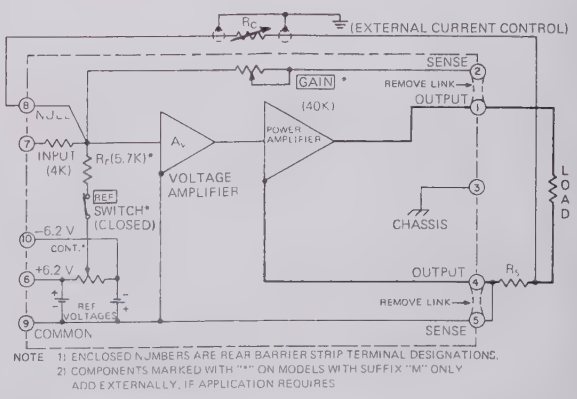
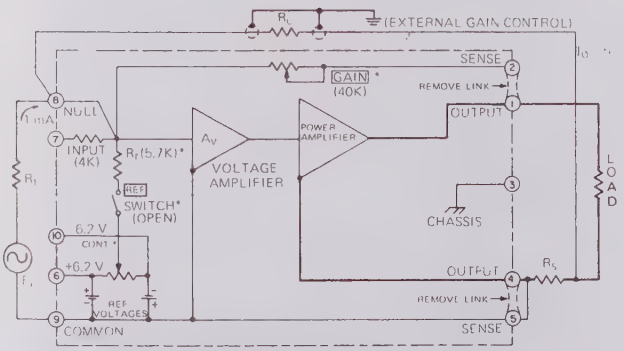


FIG. 3-16 STANDARD CONSTANT CURRENT REGULATOR

As indicated previously, control is possible two ways: with the built-in REF control and a fixed coupling resistor R_C (non-linear) or setting the REF control to 1 mA (either polarity) and making R_C a variable resistor (linear control). In the latter case, control can then be effected remotely by rheostat or step switches with precision resistors (programming by resistance) as described in paragraph 3-16 for the standard voltage mode operation.

3-41 CONSTANT CURRENT AMPLIFIER MODE

3-42 If the internal DC reference source is disconnected (REF switch "out") and an AC signal source is applied to the input as shown in FIG. 3-17, the BOP functions as an amplifier as described in previous paragraphs. Similar criteria for selection of feedback components and identical limitations apply as for the circuitry in the constant voltage mode. If input sources have a DC component for example, it can be either eliminated, or the output level can be shifted to accommodate the input. In these cases the REF switch is transferred to the "in" position and the DC level adjusted until the desired output wave shape is achieved, as observed with an oscilloscope parallel to the load. FIG. 3-17 shows the connections for standard amplifier operation in the constant current mode.



NOTE 1) ENCLOSED NUMBERS ARE REAR BARRIER STRIP TERMINAL DESIGNATIONS
2) COMPONENTS MARKED WITH "*" ON MODELS WITH SUFFIX "M" ONLY
ADD EXTERNALLY, IF APPLICATION REQUIRES.

FIG. 3-17 CONNECTIONS FOR CONSTANT CURRENT AMPLIFIER

3-43 Variations on the standard amplifier circuit (FIG. 3-17) to accommodate specific operating requirements can be readily implemented by calculating the external component values to suit the application. The transfer function for the constant current mode is used for this purpose:

$$I_o = I_b (R_C/R_S), \quad \text{where } I_b$$

is the control current from the input source, or

$$I_b = e_i/R_i$$

As long as I_b = 1 mA is available from the input source, the circuit shown in FIG. 3-17 may be used. Linear gain control can be achieved by making R_C a variable resistor. DC components may be added or subtracted by means of the internal REF sources, as previously described for operation in the voltage mode. If less control current is available from the input source, or higher value sensing resistors, are used for lower maximum output currents the control resistor must be recalculated. If for example our input source has a maximum amplitude of 10 V and a source impedance of 25 K ohms, the available control current is 10 V/25 K ohms = 0.4 mA. If we desire a maximum output current of 1 Ampere, the sensing resistor is selected by: $V_S/R_S = I_o$, 1 V/1 A = 1 ohm. The actual power dissipation of R_S = 1 V (1 A) = 1 watt. A ten watt wire wound unit is selected for R_S. Since a gain of I_o/I_b = 1 A/0.4 mA = 2500 is required and R_C/R_S must equal this ratio, the value of R_C equals 2500 ohms. A wire wound, precision rheostat of that value will provide linear control of the output current.

3-44 SERIES OPERATION

3-45 The BOP POWER SUPPLY/AMPLIFIER may be connected in series with an identical unit to achieve increased voltage output. Several precautions must be observed however to insure successful operation:

a) The nature of the BOP circuitry does not permit series connection with INDIVIDUAL output control. A "Master/Slave" configuration is recommended instead, operating into separate-or into a common load.

b) The "Current Limit" controls of the SLAVE supply must be adjusted to a slightly higher value then those of the MASTER supply. This will insure the necessary lead of the MASTER supply in the process of current limiting.

c) The set-up procedure described below should be followed closely. DO NOT ADJUST THE CURRENT LIMIT CONTROLS TO VALUES GREATER THAN 5.6 AMPERES (MODEL BOP 36-5) AND 1.75 AMPERES (MODEL BOP 36-1.5). Although this may be possible (due to component tolerances), increased dissipation in the pass-element sections with possible destruction of the transistors may result.

3-46 SET-UP PROCEDURE (Example for BOP 36-5)

a) PRELIMINARY ADJUSTMENTS. Since two sets of series regulator transistors are used in the BOP Power Supply/Amplifiers there are two current limit controls which are factory set to limit at a short circuit current of 5.5A DC (Model BOP 36-5) and 1.65A DC (Model BOP 36-1.5). For a series connection of two BOP units, the two current limit controls of the SLAVE supply must be re-set to limit at a slightly higher value. (To 5.6A on Model BOP 36-5 and 1.75 on Model BOP 36-1.5). This will permit the full output current from the series combination and insure proper current limiting sequence (first MASTER, then SLAVE).

b) CURRENT LIMIT ADJUSTMENTS, SLAVE UNIT. Connect an accurate ammeter, such as the Weston Model 931, across the output terminals of the unit designated as the SLAVE. Turn the REF. control fully counter clockwise and place the REF. switch in the "IN" position. Turn POWER switch "ON". Observe the external ammeter. Adjust the GAIN control until output current does no longer increase. The short circuit current will be approximately 5.5A.

c) Locate the two "I_oLIMIT" controls (R35,R37) and the "MODE switch" (S1) on the printed circuit board (refer to the location diagram, FIG. 2-1). Turn R37 slowly clockwise until the ammeter shows an increased short circuit of about 5.6A. Turn POWER switch "OFF." Reverse polarity of the external ammeter. Turn REF control fully clockwise.

d) Turn POWER "ON." The ammeter should again show approximately 5.5A. Adjust the short circuit current by turning R35 slowly clockwise until 5.6A is reached. This completes the preliminary adjustment on the SLAVE unit.

e) The two BOP units can now be series connected as shown in FIG. 3-18 or 3-19. Some load connections may require the operation of the BOP combination in the SLOW mode. Locate the MODE switch (S1) by referring to FIG. 2-1 and transfer both MASTER and SLAVE supplies to the SLOW position if AC instability occurs.

f) As seen from FIG. 3-19, the output of the SLAVE supply is completely dependent upon that of the MASTER, and in fact "tracks" the MASTER supply in an exact ratio of 1:1 if both GAIN controls are set to the same value and if R_t is selected such that:

$R_{vcs}/R_t = 1$, since:

$E_{os} = E_{om}R_{vcs}/R_t$ where:

E_{om} = Output Voltage, "Master"

E_{os} = Output Voltage "Slave"

R_t = Tracking Resistor.

In this case, $E_{om} = E_{os}$, where E_{os} is the SLAVE output voltage, since $R_{vcm} = R_{vcs}$, i.e. the setting of the two GAIN controls is identical. If for example in the connection shown in FIG. 3-19, the voltage across both loads must be 30 volts, the REF. control of the MASTER is set to the desired polarity and the GAIN control to the required 30 volts. A 30K ohm resistor for R_t, connected as shown, will result in a control current of $E_{om}/R_t = 1$ mA and consequently in a SLAVE output of:

$E_{os} = 1$ mA (R_{vcs}) = 30 volts (if R_{vcs} = 30K)

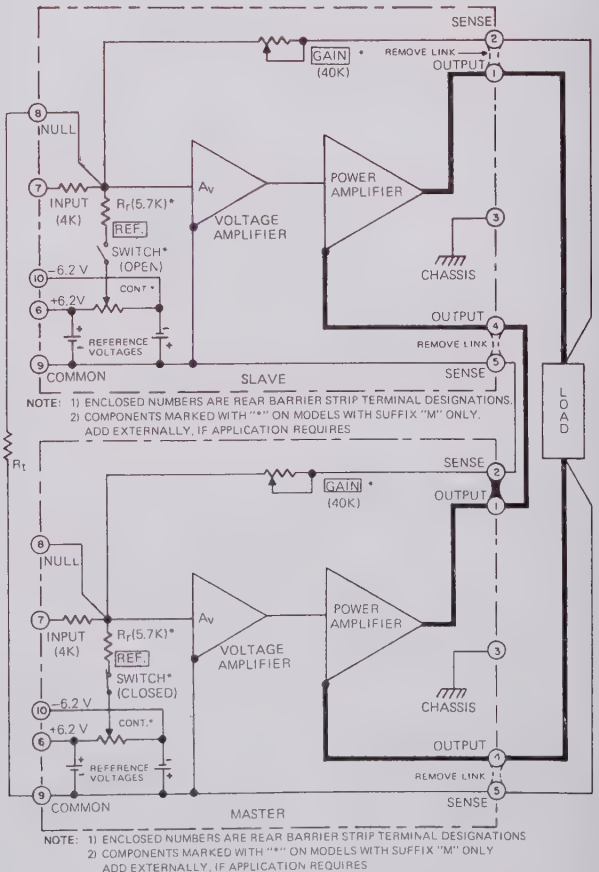


FIG. 3-18 SERIES OPERATION INTO SINGLE LOAD

where R_{VCS} is the GAIN control resistance of the SLAVE unit. Both SLAVE and MASTER output are thus equal and track in a 1:1 ratio. The tracking ratio may be altered by either changing the GAIN control settings, by replacing the built-in GAIN controls with external resistors, or by selecting the value of R_t such that the desired tracking ratio is achieved. Amplifier operation of the MASTER supply, as described in previous paragraphs may be used. The amplified output will either appear on both loads simultaneously, or if a common load is used, twice the output is applied to the load.

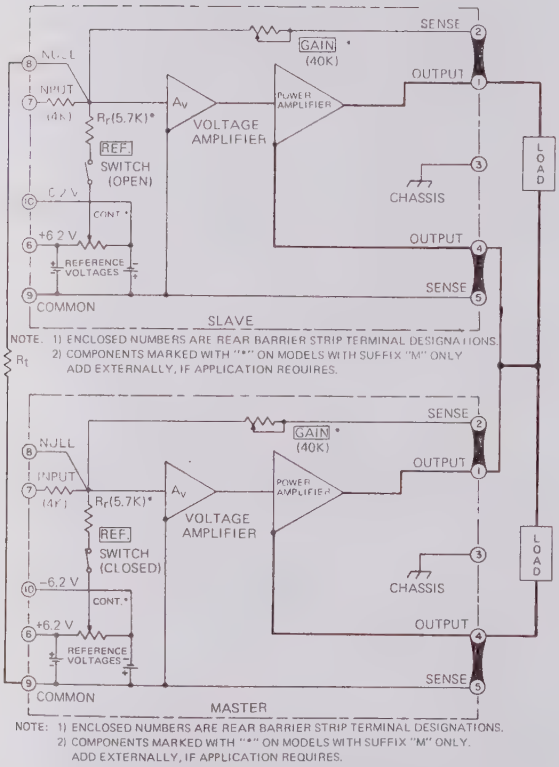


FIG. 3-19 SERIES OPERATION INTO SEPARATE LOADS

3-47 PARALLEL OPERATION

3-48 Two (or more) BOP Operational Power Supplies may be connected in parallel for increased output current delivery. As shown in FIG. 3-20, the two supplies are connected for DC constant voltage operation and can deliver twice the rated output current of a single unit. Although local control is shown, they can be remotely controlled by resistance, or operated as an amplifier as indicated previously for the single unit. Equal current sharing is achieved by selecting equal values for the current sensing resistors (R_S) and by keeping the output leads (drawn heavy in FIG. 3-20) as short as possible. For control of an output current of 5 A DC per unit, the sensing resistors (R_S) should be 0.1 ohms, 50 watt each. For other currents, R_S can be calculated to drop approximately 0.5volt for the desired maximum current. Although the individual units are protected by their current limiting circuits, a common power line connection with common AC power "on" switch is recommended.

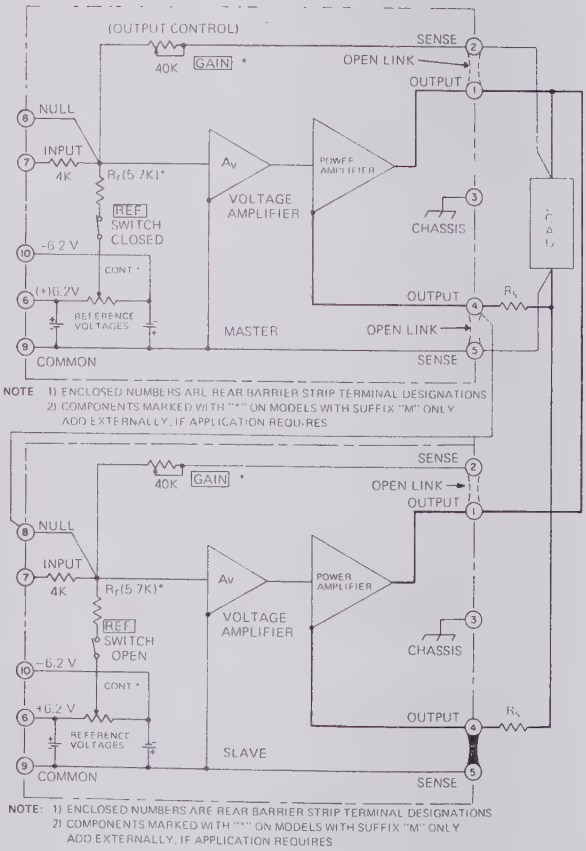


FIG. 3-20 PARALLEL OPERATION OF BOP OPERATIONAL POWER SUPPLIES

CAUTION

To avoid internal damage to series or parallel connected BOP supplies, a common a-c power line connection with simultaneous turn-on/turn-off must be provided.

SECTION IV – THEORY OF OPERATION

4-1 GENERAL

4-2 This section contains a short review of the principles of "operational" theory with special reference to the BOP Operational Power Supply/-Amplifier. The scope of this manual allows only a simplified mathematical analysis and the standard texts on linear amplifiers and feedback techniques should be consulted if a more extensive treatment is desired.

4-3 ANALOGY POWER SUPPLY – AMPLIFIER

4-4 Operational amplifiers are high-gain, DC coupled amplifiers, which when internally stabilized and used in a closed loop configuration, exhibit linear gain characteristics depending only on the external feedback components.

4-5 Since a modern DC regulated power supply contains such an amplifier in a closed loop arrangement and in series with a power amplifier booster (consisting of driver stages and series regulators) it can be used as an amplifier if several conditions are full-filled:

1) The large, bandwidth restricting output and feedback capacitors (C_O and C_f) must be removed.

2) The amplifier must be stabilized with lag networks for a gain/frequency roll-off of 6 dB per octave.

3) The input of the amplifier must be made accessible.

The result is an "Operational Power Supply/-Amplifier", which may be analyzed in operational terms and used either in the DC power supply mode (when connected to a DC reference source) or as an amplifier with external input sources. (Refer to FIG. 4-1)

4-6 In the BOP, all of the above conditions have been satisfied. In addition, this instrument contains bipolar, precision DC reference sources and a push-pull output stage, providing (see FIG. 4-1):

1) Continuous DC output from its maximum rated negative output voltage, over zero, to its maximum rated positive output voltage.

2) With the DC reference disconnected, and an AC input source, high power bi-polar AC output with a peak to peak amplitude of twice the rated DC output.

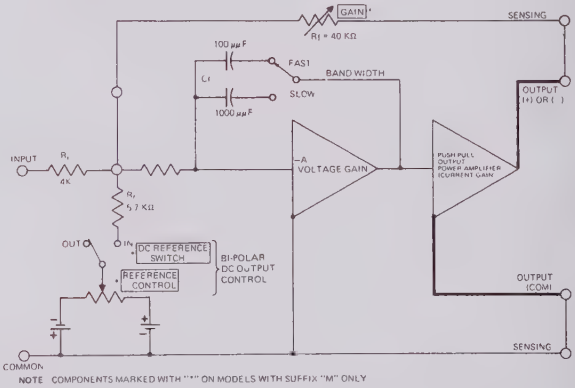
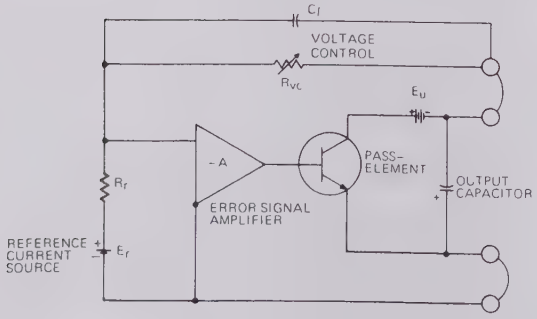
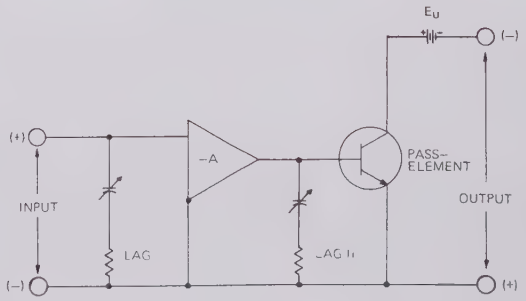


FIG. 4-1 BOP OPERATIONAL POWER SUPPLY, SIMPLIFIED DIAGRAM



a) POWER SUPPLY



b) AMPLIFIER

FIG. 4-2 POWER SUPPLY/AMPLIFIER CONVERSION

3) Combined AC and DC outputs, using the internal references as bias or level shifting sources with simultaneous AC input signals in a summing configuration.

4-7 THE IDEAL AMPLIFIER

4-8 For the purpose of analysis, an ideal model of the operational amplifier is proposed and the following assumptions are made:

1) The input terminal (null junction) will not conduct current to or from the amplifier.
2) The open loop gain is very large ($A \rightarrow \infty$).
3) The input voltage ϵ approaches zero when the feedback loop is closed. ($\epsilon \rightarrow 0$)

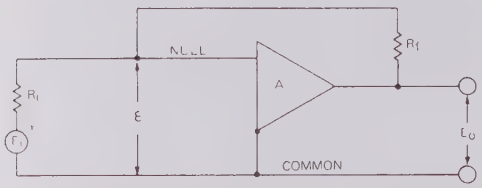


FIG. 4-3 MODEL OF IDEAL OPERATIONAL AMPLIFIER WITH FEEDBACK (INVERTING CONFIGURATION)

4-9 Refer to FIG. 4-3. Since (by the previous assumptions) the currents in R_f and R_i are equal, Kirchhoff's loop equation may be written as:

$$\frac{E_i - \epsilon}{R_i} + \frac{E_o + \epsilon}{R_f} = 0;$$

By definition, $E_o = -A\epsilon$, where A represents the "open loop" gain. Also:

$$\epsilon = \frac{E_o}{A}.$$

If we let $A \rightarrow \infty$, $\epsilon \rightarrow 0$, then the original loop equation reduces to:

$$\frac{E_i}{R_i} + \frac{E_o}{R_f} = 0,$$

or in the more familiar form:

$$E_o = -E_i \frac{R_f}{R_i},$$

which is recognized as the (ideal) transfer function of an operational amplifier in the inverting configuration.

4-10 THE PRACTICAL AMPLIFIER

4-11 The closed loop relationships derived for the ideal model of the operational amplifier may be applied to the practical case with very small predictable errors which in addition can be compensated for. The "ideal" amplifier equation (2) for example may be used to calculate the magnitude of the feedback and input components with negligible errors which will be well within the component tolerances. In evaluating the DC performance however, these errors can not be neglected.

4-12 AMPLIFIER OFFSETS. In developing the ideal amplifer model, we tacitly assumed the null junction voltage and current to be zero, causing the "ideal" equation (2) to be valid. In reality however, nonidealities do exist at the null junction or input terminal of the amplifier. These errors are of the form of an offset voltage (E_{io}) and an offset current (I_{io}). The modified version of the amplifier model can be shown with these error sources as in FIG. 4-4.

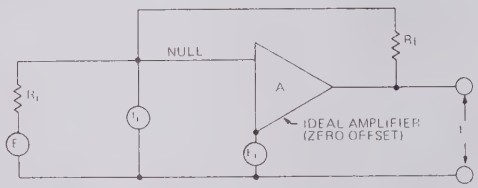


FIG. 4-4 AMPLIFIER WITH INPUT OFFSET SOURCES

4-13 Although the initial values of both offsets may be zeroed by compensating sources of opposite polarities (as in the BOP), their VARIATIONS with AC input line, output load, temperature and time do appear at the input and are specified as ΔE_{io} and ΔI_{io} in Section I, and repeated here:

SPECIFICATIONS	CHANGE IN OFFSET VOLTAGE ΔE_{io}	CHANGE IN OFFSET CURRENT ΔI_{io}
LINE (105 to 125 V AC)	< 0.1 mV	< 10 nA
LOAD (No Load to Full Load)	< 1 mV	< 10 nA
TIME (8 Hours)	< 0.1 mV	< 50 nA
TEMPERATURE (Per °C)	< 0.05 mV	< 50 nA

4-14 Considering both offset variations, the modified expression for the output voltage (with the initial or fixed parts of E_{io} and I_{io} nulled) becomes: *

$$\underbrace{E_o = E_i \frac{R_f}{R_i}}_{\text{Ideal part}} \underbrace{\pm \Delta E_{io} \left[\frac{R_f}{R_i}\right]}_{\text{Output error due to offset-voltage}} + \underbrace{\Delta I_{io} R_f}_{\text{Output error due to offset-current}} \quad \text{(Eq. A)}$$

*The error term : $\pm\left[\Delta E_i \frac{R_f}{R_i}\right]$ is considered a secondary effect in this analysis.

As seen from equation (A), the offset voltage variations (ΔE_{io}) are multiplied by unity, plus the gain ratio R_f/R_i to obtain its contribution to the output voltage change, while the offset current variations are multiplied by the value of the feedback resistor (R_f). The separation of the specifications for ΔE_{io} and ΔI_{io} not only allows an analysis of the contributions from each offset variation, but also permits component selection such as to minimize the effects of either offsets or find an acceptable compromise.

4-15 Practical examples will illustrate the usefulness of the concept:

a) For an application requiring a gain of 10, an operational programming circuit is to be set up with a Model BOP 36–5(M). From the table of specifications, the offset variations for AC source changes (105–125V AC) are:

$$\Delta E_{io} = 0.1\ mV$$
$$\Delta I_{io} = 10\ nA$$

If we let $R_i = 100K$ ohms, then for $R_f/R_i = 10$, we need $R_f = 1$ megohm. The expected output variation due to AC line changes are (from Eq. A):

$$\Delta E_o \text{ vs line} = \Delta E_{io}\left[\frac{R_f}{R_i} + 1\right] + \Delta I_{io} R_f$$

$$\underbrace{= 0.1mV\ (10+1)}_{= 1.1mV} \quad \underbrace{+ 10mA\ (10^6 \text{ohms})}_{+ 10mV}$$

ΔE_o due to offset voltage-change | ΔE_o due to offset current-change

The contribution of ΔI_{io} are seen to be almost ten times that of ΔE_{io}, due, of course, to the choice of a relatively large feedback resistor. Generally, in low gain applications, it is wise to select lower values for the feedback and input resistors if the loading on the input source will permit it; if for example:

$$R_i = 10\ K \text{ and } R_f = 100\ K$$

(retaining the previous gain ratio of $R_f/R_i = 10$), ΔI_o would only be 1 mV, calculated similar to the previous results.

b) Using the same amplifier in application with a required operational gain of 100, we select R_i to be 1 K ohm and $R_f = 100K$, thus establishing the desired gain ratio ($R_f/R_i = 100$). For the choice of input and feedback elements, we find the output variations due to AC input source changes to be:

$$\Delta E_o = \underbrace{0.1mV\ (100+1)}_{= 10.1mV} + \underbrace{10mA\ (10^5 \text{ ohms})}_{+ 1mV}$$

ΔE_o due to offset voltage-change | ΔE_o due to offset current-change

In this case the contribution from ΔE_{io} is dominant. Its effect can only be reduced by externally limiting wide variations of the AC line voltage. Similar calculations to the above examples may be made to predict the effects of load changes, temperature variations or stability (changes in output voltage with time).

4-16 GAIN-FREQUENCY CHARACTERISTICS

4-17 (Refer to FIG. 4-1) A flat frequency response to greater than 500K Hz is readilty obtainable from the push-pull power amplifiers since no voltage gain is requested from this part of the BOP. Since the voltage amplifier is stabilized with internal resistor/capacitor networks, the frequency characteristics is determined by R_iC_f only. C_f can be selected by an internal slide switch for two unity gain cross-over frequencies. In the SLOW position, the instrument is unconditionally stable for any closed loop gain (including 100% feedback) and for any amount of capacitive loading at the output. The maximum full power frequency response in this position is approximately 1.8 kHz. In the wide band position (FAST) capacitive loading is restricted to 0.001 μF, maximum. In this position however, with a unity gain cross-over frequency of 400 kHz, the instrument is still stable for any closed loop gain, including 100% feedback. As seen from the gain vs. frequency plot (Bode-plot) shown in FIG. 4-5, the theorectical frequency response of the instrument with, for example a closed loop gain of 10 (20 dB) is (in the FAST position), approximately flat to 40 kHz. However, due to capacitive loading at the amplifier output, actual frequency response is about 20 kHz.

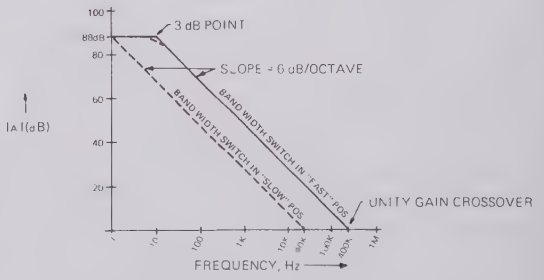


FIG. 4-5 GAIN/FREQUENCY (BODE) PLOT, BOP

4-18 CIRCUIT DESCRIPTION (Refer to Main Schematic, FIG. 6-6)

4-19 This section contains a description of the major electrical circuitry of the KEPCO BOP Operational Power Supply/Amplifier. The BOP consists of a MAIN CHASSIS assembly with attached front panel, a HEAT SINK assembly and the AMPLIFIER, DRIVER* and the AUXILIARY assemblies, all interconnected by printed circuit plugs with the rest of the circuitry. The interconnecting diagram (FIG. 6-1) represents a symbolic illustration of all plug-in connections. The identification of all connectors coincides with that of the main schematic diagram. Component numbers as shown on the main schematic are grouped as in FIG. 6-1.

*Model BOP 36—1.5(M) does not have a seperate driver assembly.

4-20 AC INPUT CIRCUIT

4-21 AC line power is introduced through a three-wire (detachable) safety line cord, with a three-prong plug. The third (green) wire of the line cord connects to the metal chassis of the instrument. If a grounded outlet and the provided line cord is used, the chassis of the instrument is grounded automatically.

If the AC POWER swtich (S201)* is closed, DS101* will energize, and the line power is applied to the fan motor (B201) and the primary windings of the main transformer (T201) and the auxiliary transformer (T202). The dual windings of T201 are either in parallel (2 jumpers from terminals 2 to 3 and 5 to 6) for 115V AC nominal AC line or in series (1 jumper from terminal 3 to 4) for 230V AC nominal line operation. The auxiliary transformer (T202) receives its power simultaneously, and is always connected to 115V AC, regardless how the main transformer is connected. The "slow-blow" type fuse (F201) protects the primary circuit from excessive current.

*On models with suffix "M" only.

4-22 MAIN DC SUPPLIES

4-23 The DC output power is derived from the secondary of the main transformer (T201). The dual secondary, with individual full wave rectifiers (CR201 to CR204 on Model BOP 36-5, single bridge rectifier CR201 on Model BOP 36-1.5) and LC filtering provides the positive (C203,L202,C204), and the negative (C201,L201,C202) raw DC sources. The two input capacitors are paralleled by two bleeder resistor (R205,206). The main DC supplies deliver the output power through the series regulators (push-pull amplifier stage).

4-24 SERIES REGULATOR STAGES (PUSH-PULL AMPLIFIER STAGE) AND DRIVER

4-25 The power transistors are located on a special, high efficiency heat sink assembly (A5 on BOP 36-5, A4 on BOP 36-1.5) and cooled by a fan (B201).

4-26 Connected as a single-ended push-pull amplifier stage and biased for class AB operation, the complementary connection of PNP and NPN power transistors eliminates the need for an inverting stage or for output transformation. The NPN type power transistor (Q501 through Q506 for BOP 36-5, Q401 and Q402 for BOP 36-1.5) are in series with the positive main DC source, while the PNP group (Q507 through Q512 for BOP 36-5, Q406 and Q407 for BOP 36-1.5) is in series with the negative main DC source, The base drive for the push-pull amplifier stage is derived from the main driver transistor (Q403), which in turn is driven by the main amplifier output stage (Q5) or by signals from one of the current limit stages (Q8,Q9).

4-27 A constant current generator stage (Q401 for BOP 36-5, Q404 for BOP 36-1.5) furnishes a bias current through the three rectifier diodes (CR501,502,503 for BOP 36-5, CR401,402,403 for BOP 36-1.5). The voltage drop developed across these diodes is such as to avoid complete cut-off for the push-pull power stage and thus prevent cross-over distortion when amplifying a sine wave.

4-28 CURRENT LIMITING

4-29 Bipolar output requires current limiting when the output is positive (NPN transistors conducting) and when the output is negative (PNP transistors conducting). A positive output current produces a voltage drop across the sensing resistor (R210 for BOP 36-5, R314 for BOP 36-1.5) which increases with increasing output current. The current limit adjustment (R35) is pre-set such that Q8 is biased "on" if the output current reaches the rated maximum value. As Q8 turns "on", the collector potential on the final amplifier stage is pulled towards the (positive) output, thereby sucessfully reducing the drive to the NPN pass-elements. As the output is further lowered by this action, the

drive to the pass-elements is further reduced until finally the NPN pass-elements are "cut-off". The action for negative output is similar to the events described above. As the PNP pass-elements are producing negative output, the output current is monitored by the sensing resistor (R207 for BOP 36-5, R311 for BOP 36-1.5). As the pre-set voltage drop (equivalent to the maximum rated current) across the current limit adjustment (R37) is reached, Q9 is biased "on". Acting on the constant current source (Q401 for BOP 36-5, Q404 for BOP 36-1.5) via Q302, the drive to the PNP pass-elements is more reduced until complete cut-off is achieved.

4-30 AMPLIFIER

4-31 Since the power transistor section has no voltage gain, the voltage amplifier in the BOP must produce the full output swing. (±36 volts) of the instrument. The amplifer consists of an input stage, several stages of voltage amplification and an output stage. A matched pair of transistors on a common substrate (Q4) is used to provide maximum thermal stability. A discrete pair of transistors (Q3,Q7) on a common heat sink, provides voltage amplification and preserves thermal stability. Q6 is another stage of voltage amplification, working into the output stage (Q5) in the configuration of an emitter follower. The total phase-shift of the amplifier is therefore 180°.

4-32 In the amplifier mode, the external input signal is introduced via the NULL junction or the INPUT terminal and amplified as described above. In the power supply mode of operation, the input is connected to a extremely stable reference source (bipolar, selectable, either positive or negative, CR6,CR7) via S101* and simultaneously to the output via the gain control (R102).* A condition of equilibrium, exists if:

$$\frac{E_r}{R_r} = \frac{E_o}{R_f}, \quad \text{where:}$$

E_r = Reference Voltage

R_r = Reference Resistor

E_o = Output Voltage

R_f = Gain Control

In this condition, no "error signal" exists and the output remains constant. If however a change in output voltage takes place (due to load change) or the AC input changes (tending to change E_r) an error signal is produced, amplified and applied to the power amplifier or series regulator in such a way as to change the voltage drop across them, thus re-establishing the conditions given by the equilibrium equation above. Similar action takes place if either R_r or R_f are varied, thus allowing the extablishment of output levels by means of value changes in either R_r or R_f (used to advantage in the BOP, R_f and R_r are the GAIN and REF. control respectively made accessible as high-resolution controls at the front panel).*

4-33 Permanently connected to the amplifier input are the offset controls (E_{io} null, R203 and I_{io} null, R204). These controls are accessible through the front panel and can be adjusted in a manner described in Section V. Amplifier offsets have been discussed previously (See par. 4-12).

4-34 AC considerations. A single AC feedback loop in the voltage amplifier, connected from the input stage (emitter of Q4) to the output (base of Q5) is used to achieve the two specified gain/frequency characteristics for the BOP (See FIG. 4-5). In the "SLOW" position of the mode switch (S1) a larger feedback capacitor (C3) provides for unconditional instrument stability under all conditions, including 100% feedback and unrestricted capacitive loading. In the "FAST" position of the mode switch a smaller feedback capacitor is used, enhancing the bandwidth but restricting capacitive loading of the instrument to 0.001 μF.

4-35 METERING CIRCUIT*

4-36 The panel meter (M101) provides for continuous monitoring of either DC output voltage, DC output current or rms output voltage, selectable on S202. In the "DC output voltage" position (S202 pos. "E_o") the meter is connected in series with the multiplier resistor (R39) across the error sensing leads, which in turn are either directly connected to the output by the provided links, or when using remote sensing, are connected to the load. In the "DC output current" position (S202 pos. "I_o") the meter is connected in parallel to the current measuring resistor (R201 for BOP 36-5, R315 for BOP 36-1.5) which is in series with the output lead. In this position, the meter will indirectly measure the DC output current which is proportional to the voltage drop across the measuring resistor. In the "AC output voltage" position(S202 pos. "E_{rms}") the meter is connected across a full wave rectifier bridge (CR10), which in turn is connected across the error sensing terminals, as in the DC output voltage position. The calibrating rheostat (R18) allows exact calibration in the "E_{rms}" position.

4-37 AUXILIARY CIRCUITS

4-38 OUTPUT STAGE POWER SUPPLY. This supply is derived from a secondary on the auxiliary transformer (T202). It is a full wave, dual supply (± 60 V DC), rectified by CR304, CR305 (posi-

*On models with suffix "M" only.

tive supply) and CR302, CR303 (negative supply). The supplies are capacitor filtered by C303 and C302 respectively. This DC source provides the operating potentials for the output stage transistors (Q5,Q6,Q10).

4-39 AMPLIFIER POWER AND REFERENCE SUPPLY. This full wave rectified (CR301) and capacitor filtered (C301) power supply is derived from a secondary on T202. A constant current stage (Q1) feeds a string of four zener diodes (CR2 through CR5) from which the operating voltages for the input stage as well as the positive and negative reference voltages are derived. The reference zener diodes (CR6,7) are temperature compensated devices. If the reference switch (S101)* is closed, a DC control current (I_b) is derived from those diodes, the polarity and magnitude of which depends on the position of the wiper on the reference control resistor (R101).* The DC control current range adjustable on the reference control is from (-) 1 mA to (+) 1 mA. The amplifier offset controls (R203,204) are also connected across the reference voltages. In addition, both reference sources are made available at the front panel* and at the rear barrier strip (TB201).

4-40 OVERSHOOT PROTECTION CIRCUIT. To prevent overshoot at turn-off or power failure, special circuitry has been provided to discharge the main filter capacitors and shunt down the instrument. A small DC power supply, derived from a secondary on the auxiliary transformer (T202) and consisting of bridge rectifier CR306 and filter capacitor C304 is connected to sense low voltage conditions or sudden power loss, turn-off action of power failure. As soon as a drop in the voltage divider (R303,305) is sensed, the amplifier stage (Q303) is biased towards cut-off, thus producing a firing pulse to the silicon controlled rectifier (CR205 for BOP 36–5, CR309 for BOP 36–1.5). The SCR which is connected across the total main supply, effectively shorts the main supply, simultaneously energizing the relay (K301 for BOP 36–1.5, F301 for BOP 36–1.5), which in turn shuts off the instrument. CR308 and C307 prevent immediate reapplication until the filter capacitors in the main supply are discharged (approximately 2 seconds).

*Models with suffix "M" only.

SECTION V – MAINTENANCE

5-1 GENERAL

5-2 This section covers maintenance procedures and calibration of the BOP Operational Power Supply/Amplifier, as far as not covered previously in this manual. Conservative ratings of components and non-congested lay-out should keep maintenance to a minimum. If trouble does develop however, the easily removed wrap-around cover in conjunction with the plug-in feature of all major component boards provide exceptional accessiblity of the circuitry.

5-3 COVER REMOVAL

5-4 The wrap-around cover may be readily removed by loosening the two (2) holding screws on the top of the front panel and holding screws on each side of the unit.

5-5 FAN MOTOR

5-6 The fan motor in the BOP has permanently lubricated bearings and does not require maintenance. The inside of all BOP's should be cleaned periodically to insure full cooling efficiency.

5-7 INTERNAL ADJUSTMENTS

a) CURRENT LIMIT CONTROLS. The output current limit controls (R35,R37) are factory adjusted to limit the output current at 10% above the maximum rated value. Calibration is necessary only if components associated with the current limit circuitry have been replaced or, if a lower limit is desired. The current limits are individually adjustable in the range from 65% to 110% of the maximum rated output current. The current limit potentiometers are located on the amplifier printed circuit board (PCB 1-A1, see FIG. 2-2 for location) and are readily accessible from the top of the unit. Adjustment takes place as follows:

1) Connect BOP as a power supply for negative output. Connect load, so that the desired output current (plus 10%) is drawn from the unit.

2) Observe output ripple on the oscilloscope across the load. Turn "I_o Limit" control (R37) counter clockwise until the output ripple sharply increases. (This is the point at which current limiting takes place) Turn R37 slightly clockwise until the output ripple appears just normal again.

3) Repeat above procedure by transferring to a positive output and adjusting R35 as described above. The current limit is now set to the new value.

b) METER CALIBRATION.* The built-in panel meter has been calibrated at the factory (in the "E_{rms}" position) for correct indication of the AC output voltage using a true rms indicating reference. The meter may be re-calibrated to any other reference desired by monitoring the output with the reference source and adjusting the calibrating rheostat (R18, see FIG. 2-2 for location).

*Models with suffix "M" only.

5-8 TROUBLE SHOOTING

5-9 The repair of precision power supplies and operational amplifiers requires a thorough understanding of the operational concept, experience with solid state circuitry, and appreciation of the problems encountered in closed–loop systems. Repair beyond simple part replacement and recalibration should therefore be handled only by personnel familiar with these concepts. "Trouble Shooting Charts", giving resistance and voltage ratings at various parts in the circuitry are of little value in feedback amplifiers and for this reason not included here. Presented instead are:

a) Extensive Operational Theory (Section IV)

b) Parts Location Diagrams (Section VI)

c) Main Schematic with Voltage Readings on all essential points. (Section VI)

d) Parts List (Section VI)

e) Circuit Description (Section IV)

It has been our experience that this material will provide the necessary information in the majority of all cases of equipment failure. The following basic trouble-shooting steps may also be found helpful:

a) Disconnect BOP from the a-c input source, from the load and from all auxiliary sources such as input signal generators, etc.

b) Restore *ALL* jumper links on the rear barrier-strip and reconnect BOP to a-c power input.

c) Perform the PRELIMINARY ELECTRICAL CHECK, as described in Section II of this manual. If the BOP functions as described in this operating mode, the trouble or malfunction must be traced to external causes or interface problems. Check all interconnecting wires between the input sources and the BOP and all load and error-sensing wiring between the BOP and the load. If the BOP does ***not*** function in the standard power supply mode, determine the failure mode (no output, high output or poor performance) and check as follows:

d) NO OUTPUT. Check a-c input source for prevailing line voltage. Refer to A-C INPUT REQUIREMENTS as presented in Section II of this manual and check if the BOP main transformer connections are correct. (BOP is normally delivered for 115V a-c service.) Check fuse (or circuit breaker) and restore if open. NOTE: THERE IS A 2-SECOND TIME DELAY AFTER EACH A-C TURN-OFF. SEE NOTE AT END OF SECTION II IN THIS MANUAL.

e) HIGH OUTPUT. Often indicative of an open feedback loop. Recheck correct placement of error-sensing links, ***either*** at the front ***or*** at the rear (NOT both). High or unstabilized output is always accompanied by excessive output ripple and often the output voltage cannot be controlled by the standard panel (or external) controls. Localize the problem as follows:

1) Remove BOP cover and locate the TEST POINT (J1) on the main amplifier board (A1—refer to "Component Location, Main Amplifier Board A1" in Section V of this manual). Disconnect ***both*** mating jacks from the main heat sink and one mating jack from the driver assembly (not used in BOP 36—1.5) (A4, A5—refer to "Component Location, Main Chassis" in Section V of this manual).

2) Connect a short lead from the TEST POINT to the "Output Sensing" terminal (NOT to the "Common sensing" terminal). If the output of the BOP can now be controlled by the GAIN and the REF controls, as evidenced by observing the front panel meter (or connecting a suitable voltmeter to the output terminals), the voltage amplifier (including predriver stage) is operating correctly and can be eliminated from further analysis. In these cases, the main driver and output stages, located on separate heat sinks (A4, A5 in all models except BOP 36—1.5(M) where A5 is not used and the driver is located together with the output stages on the A4 assembly) must be thoroughly investigated for burned components and/or shorted power transistors.

3) If the BOP cannot be controlled locally when by-passing the main driver and output stages, as described in par. 5-9e2 above, proceed with circuit analysis by means of the "Main Schematic" (Section VI in this manual). Measure all relevant voltages and compare with listed values. Inspect printed circuit board for visual evidence of damaged components. Test transistors and repair defective components as required.

f) POOR PERFORMANCE. If the BOP is basically functioning but poor performance is evident, reinspect all external connections and test the instrument by following the instructions in the PERFORMANCE MEASUREMENTS paragraph (Section V in this manual). Poor d-c performance (excessive output effects) is often due to incorrectly connected load, instrumentation or faulty measurement techniques. Follow the recommended procedures closely and refer to the applicable diagrams. High-frequency oscillations, as observed at the output or across the load, is often due to excessive capacitive loads, when the BOP is operated in the FAST mode. Transferring the MODE switch (S1—refer to "Component Location, Main Amplifier Board A1," Section V in this manual) to the SLOW position should eliminate this condition and make the BOP stable for any load condition.

g) KEPCO FIELD ENGINEERING OFFICES AND THE KEPCO REPAIR AND APPLICATIONS ENGINEERING DEPARTMENTS ARE ALWAYS AVAILABLE FOR PROMPT SERVICE IN DIFFICULT REPAIR OR APPLICATION CASES.

5-10 TEST MEASUREMENTS

5-11 GENERAL. Test measurements to verify the specifications of the operational power supply are often required as a part of incomming inspection,

following repairs or as a part of a regular maintenance procedure. Adequate test facilities and equipment as well as great care in the performance of these measurements are of prime importance to insure valid results. Since many measurements on operational power supplies and amplifiers require specialized test equipment and rigidly controlled environment conditions, only the more readily verifiable ones are described here.

5-12 MEASUREMENT TECHNIQUES. The importance of proper interconnection of test instruments and the device under test can not be overemphasized. Indiscriminate connection of measuring devices to the output may cause erroneous readings of output effects, offset parameters or output impedance. The following recommendations should therefore be followed if measurements are made:

a) Connect equipment exactly as shown on the measurement set-up diagrams (FIG. 5-2,5-3). Do not attempt to measure performance characteristics at the front terminals, while drawing load current from the rear terminals (or vice-versa).

b) Output current measurements require the use of a high quality, wire-wound measuring resistor which should be of the four-terminal type and have a low temperature coefficient as well as a wattage rating of at least ten times the actual power dissipated (TEPRO Type TMK, or equivalent).

c) Ripple and Noise Measurements require the strict adherence to sensible equipment grounding practices. There can be only one ground point in a test set-up. All equipment is therefore operated off line ground, the equipment cases or ground connections brought to the unit under test, and the latter is then grounded at a single point.

5-13 TEST EQUIPMENT REQUIRED. The following represents a listing of equipment required to perform the suggested performance tests:

a) LINE STEP DEVICE OR VARIABLE TRANSFORMER capable of adjusting the power line from 105 V to 125 V AC and rated to deliver the maximum input current for the instrument under test.

b) RESISTOR LOAD, adjustable to load the power supply to 10%, 50% and 100% in both, voltage and current operating modes and equipped with a shorting switch.

c) VOLTAGE MONITOR. Differential or digital voltmeter with a resolution of at least 1 mV and a range covering the maximum output voltage of the instrument under test.

d) RMS READING VOLTMETER for ripple monitoring, Ballantine Model 320A or it's equivalent.

e) OSCILLOSCOPE for output ripple observance, Tektronix, Model 502B or equivalent.(Optional)

f) MULTIMETER for measuring pass element voltage and general trouble shooting measurements. 20 K ohm/V, Weston Analyzer Model 980 or its equivalent.

g) PRECISION DC AMMETER with a range covering the maximum output current of the Model under test. (Weston Model 931 or equivalent)

h) OSCILLOSCOPE, for slewing rate measurements, Tektronix Model 545A or equivalent.

i) SIGNAL GENERATOR, for slewing rate measurements, Hewlett Packard, Model 211A or equivalent.

j) DC MICROVOLT/AMMETER for offset measurements, Millivac Model MV-07C or equivalent.

5-14 DC MEASUREMENTS. Variations of the offset voltage (ΔE_{io}) and offset current (ΔI_{io}) with power line changes over the specified range are an excellent way of measuring output effects of the operational power supply. These measurements may be readily duplicated by following the instructions and diagrams below:

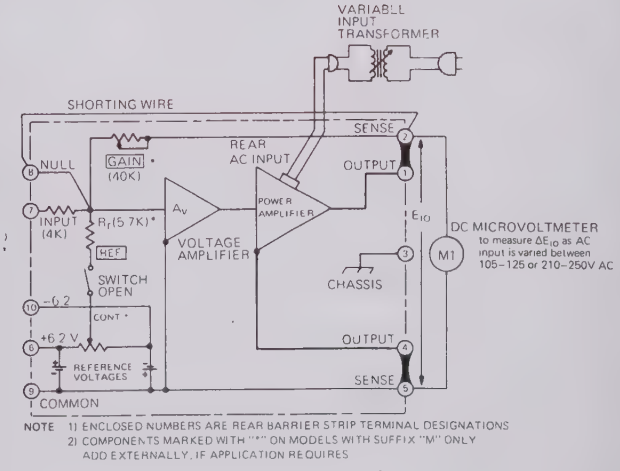
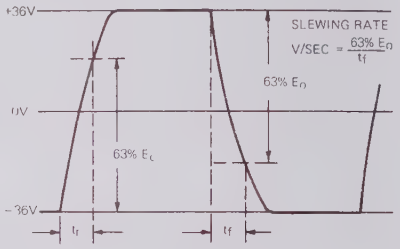


FIG. 5-1 DC TEST MEASUREMENTS (ΔE_{io} VS AC LINE)

a) Variations in Offset Voltage (ΔE_{io}). Measurements are made with the circuit shown in FIG. 5-1. Since the feedback terminals are shorted out and the input is disconnected, the operational gain is unity. Whatever offset voltage exists between null junction and common will be transfered directly to the output. Monitoring the output by means of a sensitive null detector while varying the AC line input (or temperature, or time if facilities permit) will allow measurement of ΔE_{io} at the output.

b) Variations in Offset Current (ΔI_{io}). Measurements are made with the circuit shown in FIG. 5-2. Since the offset current will have to flow through the feedback resistor and produces an output voltage E_o which is equal to $I_{io}R_f$. If this output voltage is monitored while varying the AC line input (or temperature, or time if facilities permit) will yield an indication of ΔI_{io} when the output voltage is divided by the value of the feedback resistor.

5-15 AC MEASUREMENTS. Measurement of the slewing rate of programming speed of the BOP Operational Power Supply/Amplifier is a convenient and simple way of verifying the dynamic performance of the instrument. Slewing rate is evaluated indirectly by measuring the rise and fall time at the output, as the BOP is programmed with a square wave for full output swing. FIG. 5-3 below illustrates the test set up and the output wave form to be expected. Slewing rate is calculated by measuring the fall time (worst case) of the output wave form and converting the results to volts per microseconds as shown.



a) OUTPUT WAVE FORM

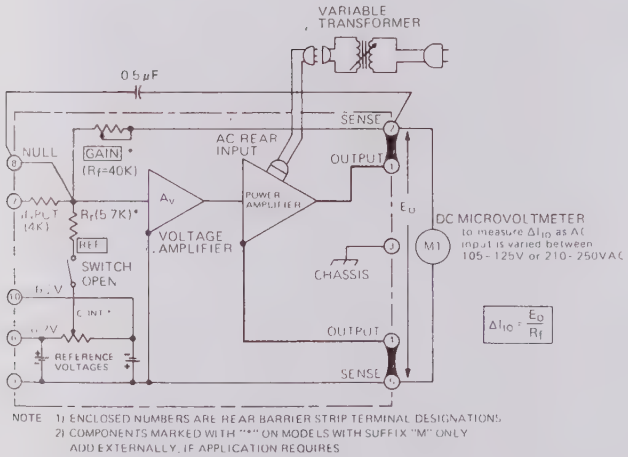
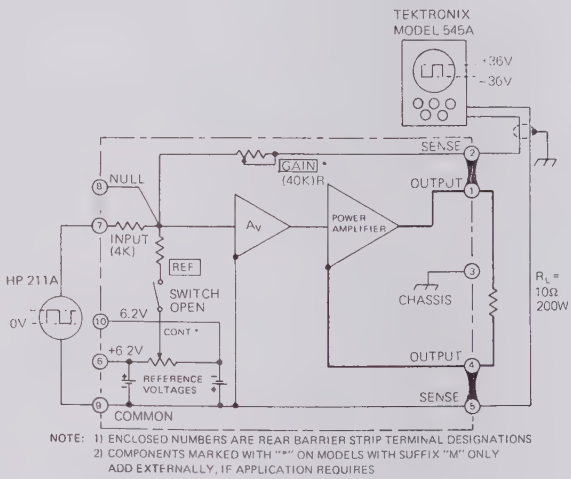


FIG. 5-2 DC TEST MEASUREMENTS (ΔI_{io} VS AC LINE)



b) INSTRUMENT SET-UP

FIG. 5-3 AC MEASUREMENTS, BOP

SECTION VI – ELECTRICAL PARTS LIST AND DIAGRAMS

6-1 GENERAL

6-2 This section contains the main schematic, the parts location diagrams, and a list of all replaceable electrical parts. All components are listed in alpha-numerical order of their reference designations. Consult your Kepco Representative for replacement of parts not listed here.

6-3 ORDERING INFORMATION

6-4 To order a replacement part or to inquire about parts not listed in the parts list, address order or inquiry either to your authorized Kepco Sales Representative or to:

KEPCO, INC.
131–38 Sanford Avenue
Flushing, N.Y. 11352

6-5 Specify the following information for each part:

a) Model and complete serial number of instrument.

b) Kepco part number.

c) Circuit reference designator.

d) Description.

6-6 To order a part not listed in the parts list, give a complete description and include its function and location.

NOTE: KEPCO DOES NOT STOCK OR SELL COMPLETE POWER SUPPLY SUBASSEMBLIES AS DESCRIBED HERE AND ELSEWHERE IN THIS INSTRUCTION MANUAL. SOME OF THE REASONS ARE LISTED BELOW:

1) Replacement of a complete subassembly is a comparatively rare necessity.

2) Kepco's subassemblies are readily serviceable, since most of them are of the "plug-in" type.

3) All active components are socket mounted, making replacement extremely easy.

4) The nature of a closed-loop power supply system requires that subassembly replacement is followed by careful measurement of the total power supply performance. In addition, depending on the function of the subassembly, extensive alignment may be required to restore power supply performance to specified values.

IF REPAIRS INVOLVING SUBASSEMBLY REPLACEMENTS ARE REQUIRED, PLEASE CONSULT YOUR LOCAL KEPCO REPRESENTATIVE OR THE KEPCO SALES ENGINEERING DEPARTMENT IN FLUSHING, NEW YORK, N.Y.

kepco REPLACEMENT PARTS LIST

AMPLIFIER ASSEMBLY (A1) MODEL BOP 36–5(M) **Code 9-1671**

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
C1	1	Capacitor,Ceramic,Disc. 47 pF, 1 KV, 10%	Sprague 5GA-Q47	117-0088
C2,4	2	Capacitor,Mica Silver Dip 100 pF, 500 V, 5%	Cornell Dubilier CD15FD101JN3	117-0673
C3	1	Capacitor,Mica Silver Dip 1,000 pF, 500 V, 5%	Cornell Dubilier CD20FD102JN3	117-0674
C5	1	Capacitor,Mica Silver Dip 150 pF, 500 V, 5%	Cornell Dubilier CD15FD151JN3	117-0675
C7	1	Capacitor,Ceramic,Disc. 330 pF, 1 K V, 20%	Sprague 3C3015BH1	117-0556
CR1	1	Zener Diode	Transitron SV125	121-0028
CR2,3,4, 5,6,7	6	Zener Diode	International Resistance 1N821	121-0041
CR8,9,13	3	Rectifier,Silicon	American Power Devices APD203	124-0435
*CR10	1	Rectifier,Silicon,Bridge	Varo EBR-W102	124-0346
Q1,8	2	Transistor,Silicon,NPN	RCA 2N3053	119-0059
Q3,7	2	Transistor,Silicon,PNP	RCA 2N4036	119-0074
Q4	1	Transistor,Silicon,NPN,Dual	Amelco 1502-122	119-0083
Q5,10	2	Transistor,Silicon,NPN	M.S. Transistor MST20	119-0079
Q6	1	Transistor,Silicon,NPN	RCA 2N2405	119-0086
Q9	1	Transistor,Silicon,PNP	Fairchild 2N4888	119-0085
R1,30	2	Resistor,Fixed,Precision,M.F. 182 ohm, 1 W, 1%	IRC CEC Type	115-2191
R2	1	Resistor,Fixed,M.G. 82 K ohm 1/4 W, 5%	IRC RG 1/4	115-2012
R3	1	Resistor,Fixed,Molded 3.9 K ohm, 1/2 W, 5%	Allen Bradley EB3925	115-0808
R5,23	2	Resistor,Fixed,Power,Axial,WW 2 K ohm, 1 W, 3%	Tepro TS-1W	115-1524
R6,7	2	Resistor,Fixed,Precision,M.F. 301 ohm, 1 W, 1%	IRC CEC Type	115-2066
R8	1	Resistor,Fixed,Precision,M.F. 3.01 K ohm, 1/4 W, 1%	IRC CEA Type	115-2214
R9,13	2	Resistor,Fixed,Precision,M.F. 1 K ohm, 1/4 W, 1%	IRC CEA Type	115-2180
R10,11, 12	3	Resistor,Fixed,Precision,WW 5.7 K ohm, 1 W, 1%	Tepro TS1W	115-1301

*Models with suffix "M" only.

NOTE:

REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS, REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.

kepco® REPLACEMENT PARTS LIST

AMPLIFIER ASSEMBLY (A1) MODEL BOP 36–5(M) Code 4-1371

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
R14	1	Resistor,Fixed,Precision,M.F. 3.01 K ohm, 1 W, 1%	IRC CES Type	115-1852
R15,17	2	Resistor,Fixed,Precision,M.F. 499 K ohm, 1/4 W, 1%	IRC CEA	115-2309
*R16	1	Resistor,Fixed,Precision,WW 5.7 K ohm, 1 W, 1%	Tepro TS1W	115-1301
*R18	1	Resistor,Variable,Cermet 5 ohm, 3/4 W	IRC Type 450-20	115-1997
*R19	1	Resistor,Fixed,Precision,M.F. 28 K ohm, 1 W, 1%	Dale MFF-1/2	115-1814
R20	1	Resistor,Fixed,Power,Axial 10 K ohm, 5 W, 3%	Tepro TS-5W	115-1635
R21,34,36	3	Resistor,Fixed,Molded 100 ohm, 1/4 W, 10%	IRC GBT 1/4	115-2231
R22	1	Resistor,Fixed,Power,Axial,WW 25 ohm, 3 W, 5%	Tepro TS3C	115-0779
R24	1	Resistor,Fixed,Power,Axial,WW 8 K ohm, 5 W, 3%	Tepro TS5W	115-1652
R25	1	Resistor,Fixed,Precision,M.F. 511 ohm, 1/4 W, 1%	IRC CEA Type	115-2260
R26	1	Resistor,Fixed,Power,Axial,WW 15 K ohm, 1 W, 3%	Tepro TS-1W	115-1414
R27,28	2	Resistor,Fixed,Molded 5.1 K ohm, 1/2 W, 5%	Allen Bradley EB5135	115-1659
R31	1	Resistor,Fixed,Molded 6.2 K ohm, 1/2 W, 5%	Allen Bradley EB6235	115-0744
R35,37	2	Resistor,Variable,Cermet 10 ohm, 3/4 W	Helipot 78PR10	115-2062
R38	1	Resistor,Fixed,Molded 10 ohm, 1/4 W, 10%	IRC GBT 1/4	115-2230
*R39	1	Resistor,Fixed,Precision,M.F. 35 K ohm, 1 W, 1/2%	Dale MFF-1/2	115-2390
S1	1	Switch, Slide	Stackpole S-26	127-0216

*Models with suffix "M" only.

NOTE:
REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS, REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.

kepco REPLACEMENT PARTS LIST

MAIN CHASSIS ASSEMBLY (A2) MODEL BOP 36–5(M) **Code 4-1371**

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
FRONT PANEL ASSEMBLY (FOR MODELS WITH SUFFIX "M" ONLY):				
DS101	1	Pilot Light Assembly	Industrial Devices Type IV	152-0089
M101	1	Meter, Volt-Amp.	Ammon FM-1	135-0456
R101	1	Resistor,Variable,WW 1 K ohm, 3 W, 3%	IRC Type 8000	115-1304
R102	1	Resistor,Variable,WW 40 K oha, 3 W, 3%	Fluke 24A-5044	115-2366
S101	1	Switch,Slide,SPST	Stackpole SS-47	127-0274

NOTE:

REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS, REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.

MAIN CHASSIS ASSEMBLY (A2) MODEL BOP 36–5(M) Code 5-770

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
B201	1	Fan,Motor	Howard Industries 23112	148-0027
C201,202 203,204	4	Capacitor,Electrolytic,Can 5.9 K μF, 75 V, +100%,–10%	G.E. 86F500-MI	117-0738
C205,206 207,208	4	Capacitor,Mylar 0.02 μF, 200 V, 10%	Sprague 192P20392	117-0377
CR201,202 203,204	4	Rectifier,Silicon	Semicon S5A4	124-0348
F201	1	Fuse, Slo Blo 5 A	Bussman MDX5	141-0042
K201	1	Relay	Line Electric MK-1027	140-0018
L201,202	2	Choke	Kepco Magnetics 100-1783	100-1783
R201	1	Resistor,Fixed,Precision,WW 0.167 ohm, 25 W, 1%	Tepro TM25W	115-2300
R202	1	Resistor,Fixed,Power,Strip 3 ohm, 20 W, 5%	Hardwick Hindle 2BRS-56-3	115-0726
R203,204	2	Resistor,Variable 20 K ohm, 1 W, 5%	IRC Type 400-20	115-2363
R205,206	2	Resistor,Fixed,Power,Axial,WW 10 K ohm, 3 W, 5%	Tepro TS-3C	115-0460
*S201	1	Switch, Slide	Stackpole SS47	127-0269
*S202	1	Switch, Slide	Stackpole SS74	127-0268
T201	1	Transformer	Kepco 100-1960	100-1960
T202	1	Transformer	Kepco 100-1961	100-1961

*Models with suffix "M" only.

NOTE:

REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS, REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.

PRE-DRIVER ASSEMBLY (A3) MODEL BOP 36–5(M) **Code 9-1671**

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
C301	1	Capacitor,Electrolytic 68 μF, 50 V	General Electric 76F02LN680	117-0511
C302,303	2	Capacitor,Electrolytic 400 μF, 75 V	General Electric 43F7573AA1	117-0432
C304	1	Capacitor,Mylar 1 μF, 200 V, 10%	Wesco 33MM	117-0395
C305	1	Capacitor,Ceramic 100 pF, 2 K V, 10%	Radio Materials Co. Type U	117-0056
C306	1	Capacitor,Electrolytic 10 μF, 6 V	Sprague 30D106G006BA2	117-0678
C307	1	Capacitor,Electrolytic 200 μF, 100 V	General Electric 43F9347AA1	117-0598
C308	1	Capacitor,Mylar,Pigtail 0.01 Mf, 200V, 20%	Gudeman Type 356	117-0353
CR301,306	2	Rectifier,Silicon,Bridge	Varo EBR-W102	124-0346
CR302,303, 304,305,308	5	Rectifier,Silicon,	Semteck SE4	124-0028
CR307	1	Rectifier,Silicon	American Power Devices APD203	124-0435
Q303	1	Transistor,Silicon,NPN	Fairchild 2N3569	119-0092
Q302	1	Transistor,Silicon,NPN	General Electric 2N336A	119-0056
Q301	1	Transistor,Silicon,NPN	M.S. Transistor MST20	119-0079
R301,302	2	Resistor,Fixed,Molded 68 K ohm, 1/2 W, 5%	Allen Bradley EB6835	115-0856
R303	1	Resistor,Fixed,Precision,M.F. 20 K ohm, 1 W, 1%	IRC CEC Type	115-2039
R304	1	Resistor,Fixed,Molded 1 K ohm, 1/2 W, 10%	Allen Bradley EB1021	115-0547
R305	1	Resistor,Fixed,Precision,M.F. 1 K ohm, 1 W, 1%	IRC CES Type	115-1822
R306,308	2	Resistor,Fixed,Power,Axial,WW 10 K ohm, 5 W, 3%	Tepro TS-5W	115-1635
R307	1	Resistor,Fixed,Power,Axial,WW 5 K ohm, 5 W, 5%	Tepro TS5W	115-0232
R309	1	Resistor,Fixed,Power,Axial,WW 2 K ohm, 5 W, 5%	Tepro TS5W	115-0568
R310	1	Resistor,Fixed,Molded 200 ohm, 1/2 W, 5%	Allen Bradley EB2025	115-0538

NOTE:

REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS, REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.

DRIVER ASSEMBLY (A4) MODEL BOP 36–5(M)

Code 12-3071

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
C401	1	Capacitor,Ceramic,Disc. 200 pF, 6 K V	Centralab DD60-201	117-0075
Q401,402, 403	3	Transistor,Silicon,NPN	RCA 2N3442	119-0070
R401	1	Resistor,Fixed,Precision,WW 5 ohm, 3 W, 5%	Tepro TS-3C	115-0700
R402	1	Resistor,Fixed,Molded 4.7 ohm, 1 W, 10%	Allen Bradley GB4701	115-0434
R403	1	Resistor,Fixed,Power,Axial,WW 30 ohm, 3 W, 5%	Tepro TS-3C	115-0773
F401	1	Fuse, 3/8 A Inst.	Bussman AGX-3/8	141-0076
PNP/NPN SERIES REGULATOR ASSEMBLY (A5)				
CR501,502, 503	3	Rectifier,Silicon,Pigtail	Semteck SE4	124-0028
Q501,502, 503,504, 505,506	6	Transistor,Silicon,NPN	RCA 2N3773	119-0091
Q507,508, 509, 510, 511,512	6	Transistor,Silicon,PNP	Motorola MJ4502	119-0107
R501,502, 503,504, 505,506	6	Resistor,Fixed,WW 0.5 ohm, 3 W, 3%	Tepro TS-3WNI	115-1880
R507,508, 509,510, 511,512	6	Resistor,Fixed,Precision,WW 0.333 ohm, 3 W, 3%	Tepro TS3CNI	115-2305
RESISTOR AND SCR ASSEMBLY (A6)				
CR601	1	Controlled Rectifier	Motorola 2N4442	124-0350
R601,604	2	Resistor,Fixed,Power,Axial 0.15 ohm, 10 W, 5%	Tepro Type TS10W	115-1795
R602,603	2	Resistor,Fixed,Power,Axial 0.083 ohm, 10 W, 5%	Tepro Type TS10W	115-1717
OUTPUT ASSEMBLY (A7)				
C701	1	Capacitor,Mylar,Pigtail 0.1 μF, 600 V	TRW X663F	117-0316
R701	1	Resistor,Fixed,Molded 10 ohm, 1/2 W, 10%	Allen Bradley EB1001	115-0502
R702	1	Resistor,Fixed,Precision,WW 4 K ohm, 1 W, 5%	Tepro TS1W	115-1637
**R703	1	Resistor,Fixed,Power,Axial,WW 1 K ohm, 3 W, 5%	Ward Leonard Type 3X	115-1302
**R704	1	Resistor,Fixed,Molded 39 K ohm, 1/2 W, 10%	Allen Bradley EB3931	115-1137

**Delete for Models with suffix "M."

NOTE:

REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS, REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.

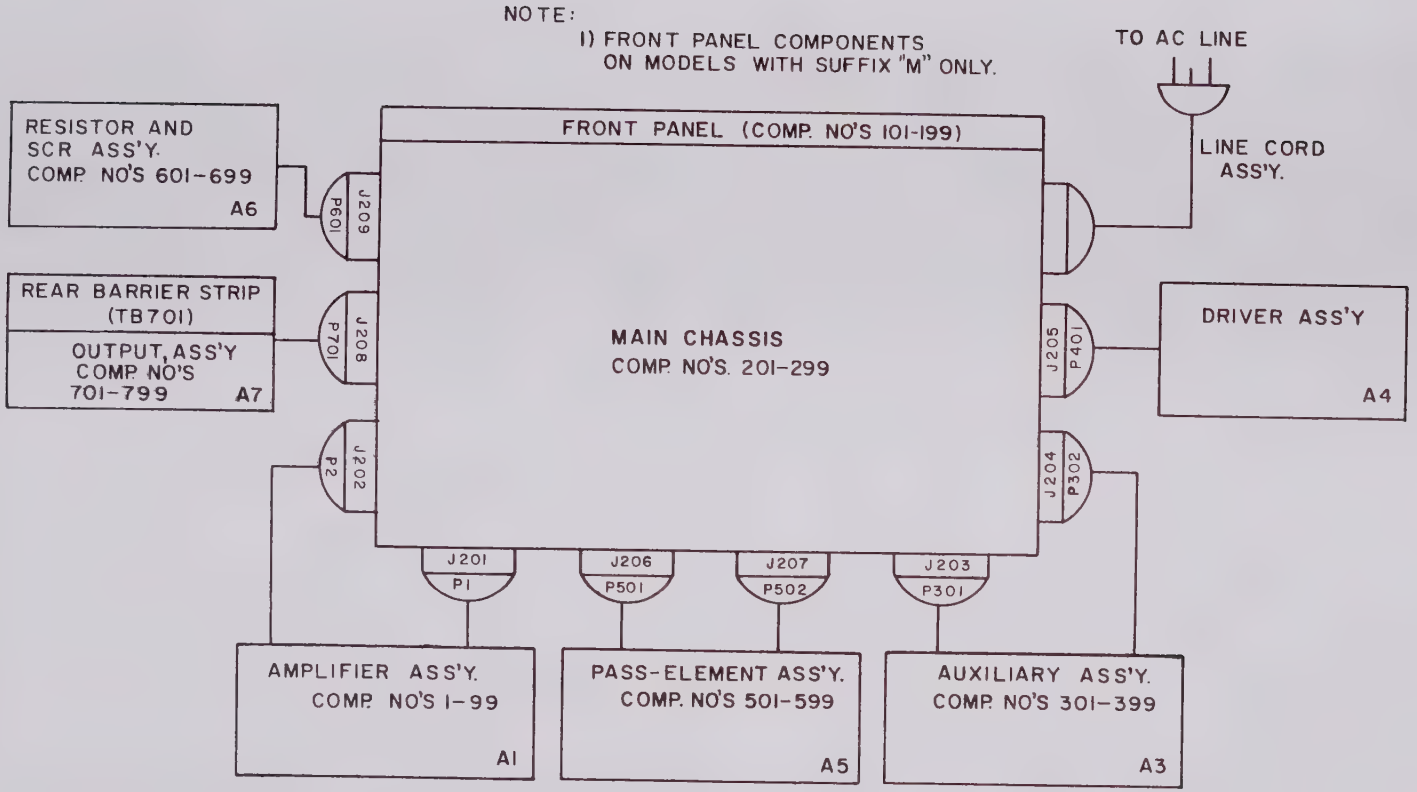
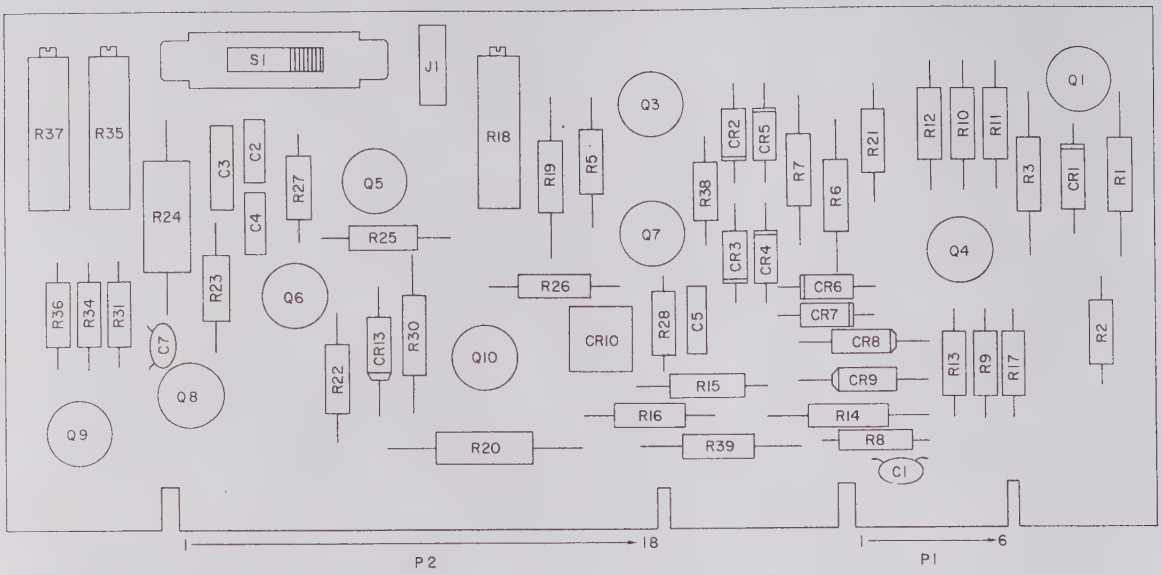
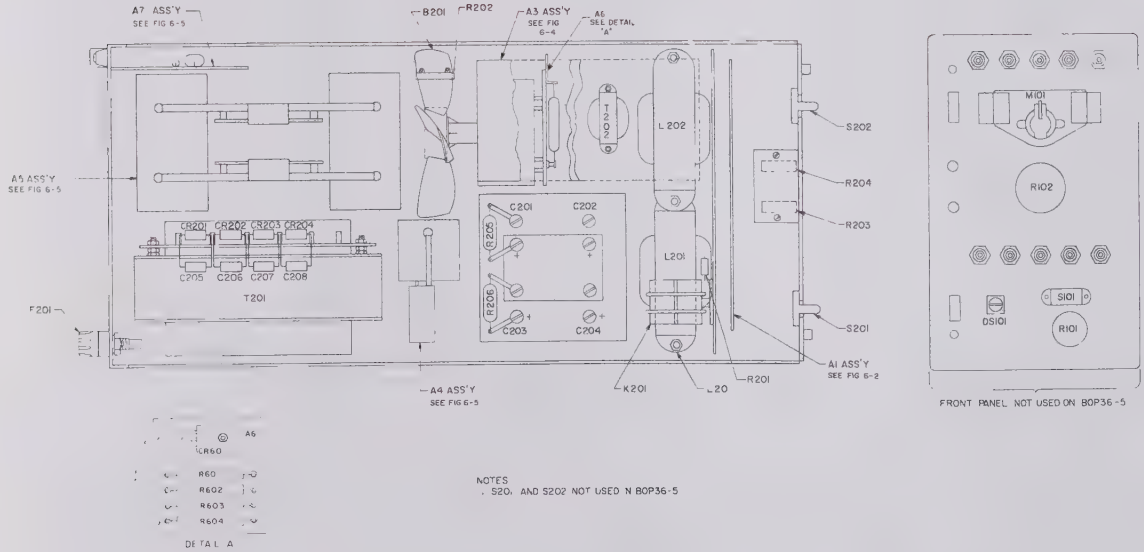


FIG. 6-1 CONNECTION DIAGRAM, MODEL BOP 36-5(M)



NOTES:
1. R16, R18, R19, R39 AND CR10 NOT USED IN BOP 36-5 (UNMETERED)

FIG. 6-2 COMPONENT LOCATION, ASSEMBLY A1



NOTES
1. S201 AND S202 NOT USED IN BOP36-5

FIG. 6-3 COMPONENT LOCATION, ASSEMBLY A2

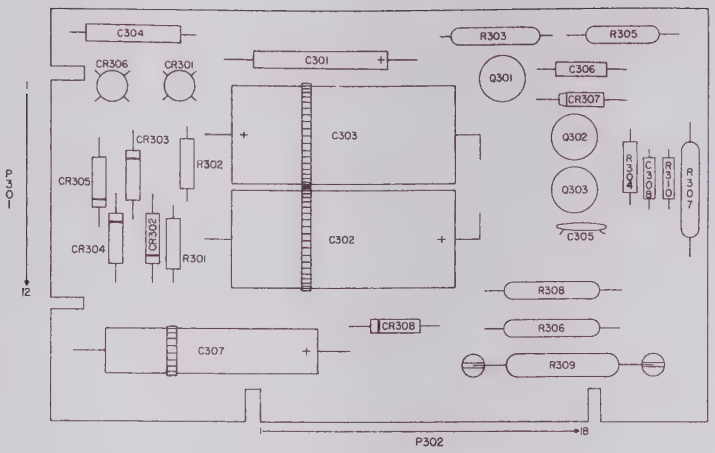
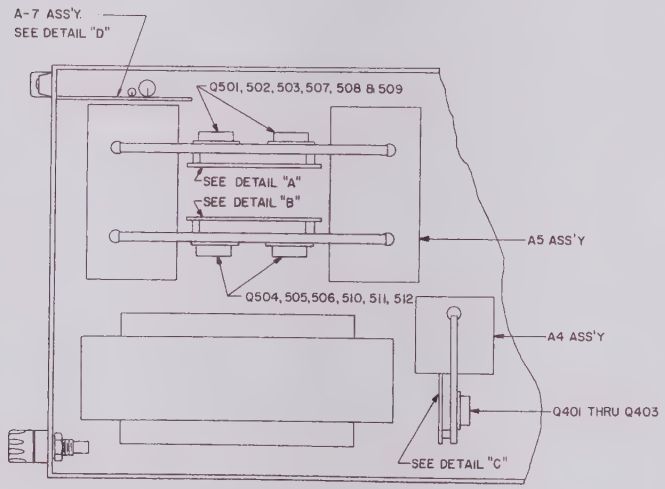
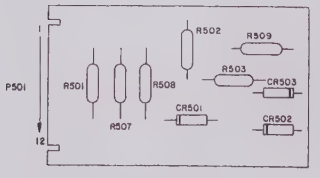
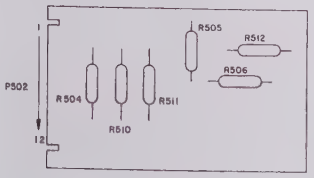


FIG. 6-4 COMPONENT LOCATION, ASSEMBLY A3







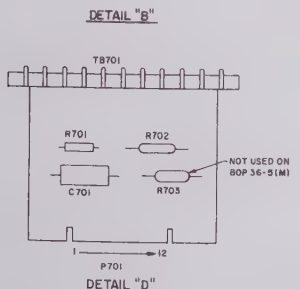
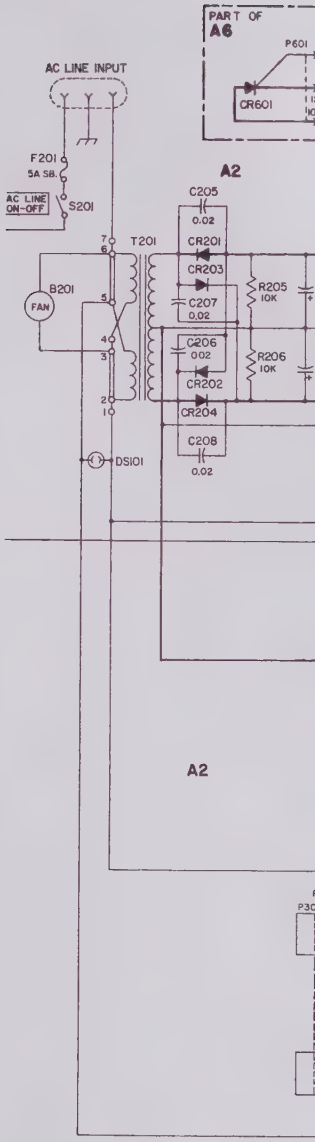


FIG. 6-5 COMPONENT LOCATION, ASSEMBLIES A4, A5, A6



ES:
1. RESISTOR VALUES IN OHMS, K = 1000
2. CAPACITOR VALUES IN MICROFARADS, EXCEPT AS NOTED.
3. VOLTAGE READINGS TAKEN UNDER THE FOLLOWING CONDITIO
   A) ZERO OUTPUT VOLTAGE, NO LOAD;
   B) SHORT BETWEEN TERMINALS (2) AND (8) ON TB701.
   C) LINE AT 115 V AC ALL READINGS WITH REFERENCE TO TE
   D) 20 K OHM/VOLT METER
   E) READINGS SUBJECT TO NORMAL COMPONENT TOLERANC
4. SWITCH LEGEND (S202):
   POS. 1 – DC CURRENT
   POS 2 – DC VOLTAGE
   POS 3 – AC VOLTAGE
5. LIST OF ASSEMBLIES:
   A) A1 – MAIN AMPLIFIER BOARD
   B) A2 – MAIN CHASSIS AND FRONT PANEL COMPONENTS
   C) A3 – PRE-DRIVER AND AUXILIARY CIRCUITS
   D) A4 – DRIVER CIRCUITS
   E) A5 – PASS-ELEMENT NPN AND PNP
   F) A6 – RESISTOR AND SCR ASS'Y.
   G) A7 – OUTPUT ASS'Y.
6. SEE PLUG-IN DIAGRAM FOR LIST OF CONNECTORS AND UNUSED PIN-NUMBERS.

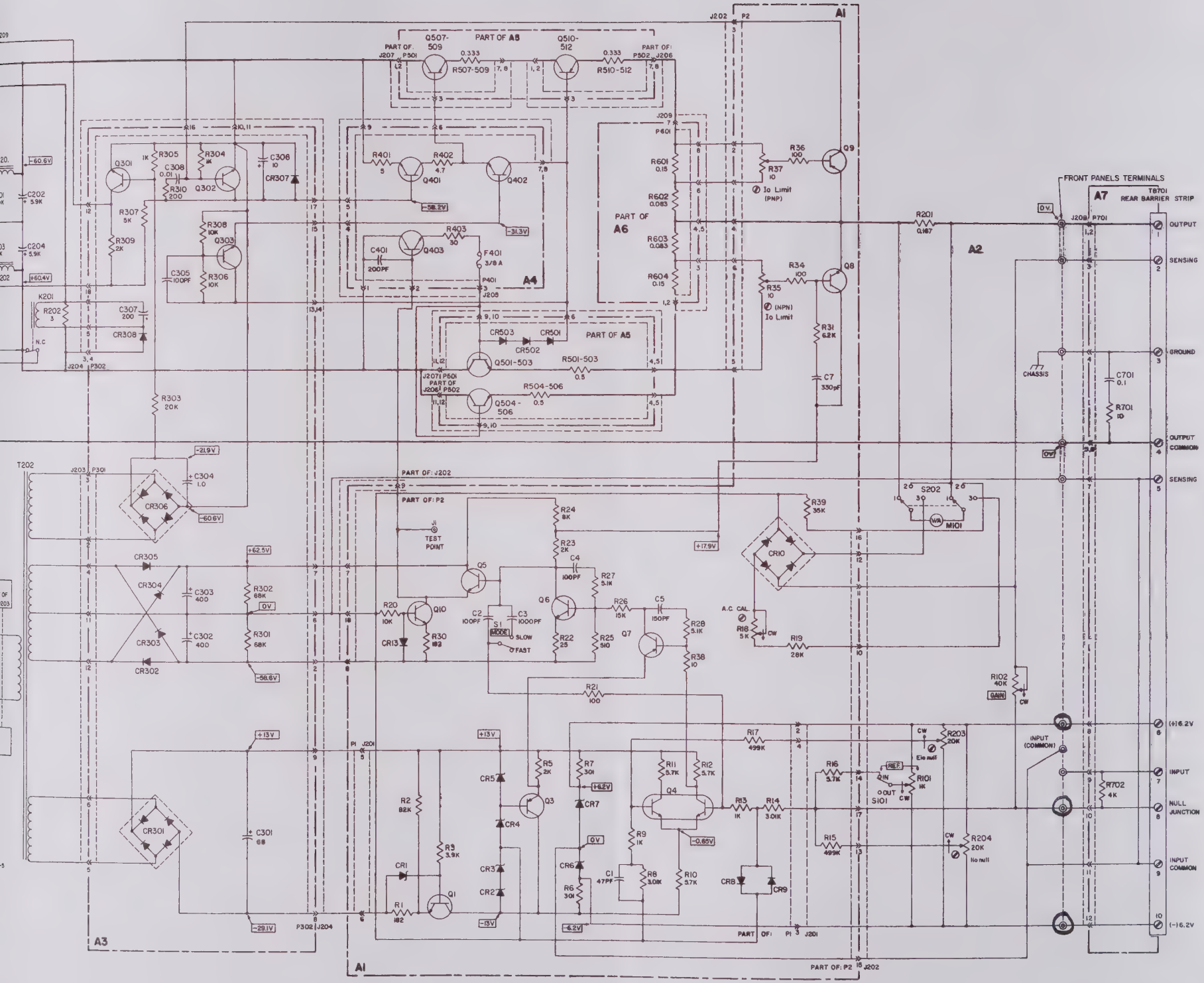


FIG. 6-6 MAIN SCHEMATIC, MODEL BOP 36-5M

KEPCO®

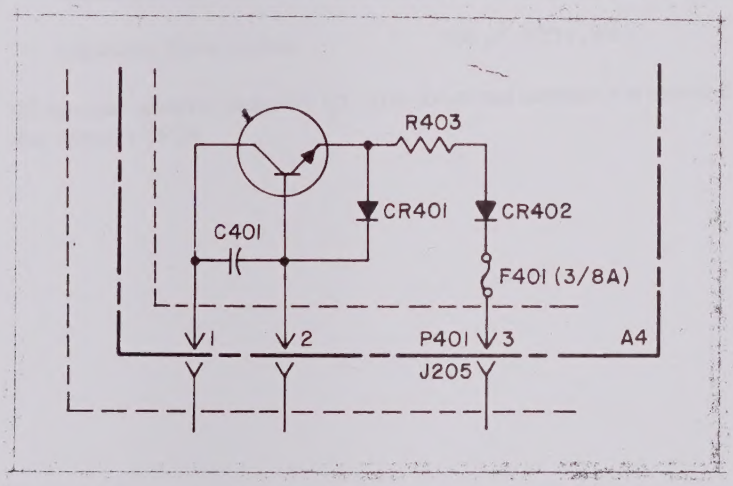
INSTRUCTION MANUAL CORRECTION

Please note the following corrections to the manual material as indicated:

Parts List and Schematic Diagram:

1. ADD:	F401	Fuse, Instantaneous, 3/8A		Kepco No. 141-0076.
2. CHANGE:	C401	Capacitor, Ceramic, Disc.	200 pF, 6 kV	Kepco No. 117-0075 to:
	C401	Capacitor, Ceramic, Disc.	200 pF, 1 kV	Kepco No. 117-0571.
3. ADD:	CR401,402	Rectifier, Silicon, Axial Leads		Kepco No. 124-0028.
4. DELETE:	R207	Resistor, Fixed, Power, Strip	10 ohm, 10 W, 5%	Kepco No. 115-1427.

5. F401, C401, CR401 and CR402 have been added to assembly A4. Main schematic has changed as follows:



6. CHANGE:	R27	Resistor, Fixed, Molded	5.1 k ohm, 1/2 W, 5%	Kepco No. 115-1659 to:
	R27	Resistor, Fixed, Molded	1 k ohm, 1/2 W, 10%	Kepco No. 115-0547.
7. ADD:	C309	Capacitor, Mylar, Axial Leads	0.001 MF, 200V, 10%	Kepco No. 117-0570.
8. CHANGE:	Q507–512	Transistor, Silicon, PNP		Kepco No. 119-0107 to:
	Q507–512	Transistor, Silicon, PNP		Kepco No. 119-0113.
9. ADD:	R311	Resistor, Fixed, Power, Axial	10 ohm, 3 W, 5%	Kepco No. 115-0421.

NOTE: R311 has been added to assembly A3. It is connected between P302–1 and the (–) end of C307.

10. CHANGE:	Q5,10	Transistor, Silicon, NPN		Kepco No. 119-0079 to:
	Q5,10	Transistor, Silicon, NPN		Kepco No. 119-0118.
11. CHANGE:	Q303	Transistor, Silicon, NPN		Kepco No. 119-0079 to:
	Q303	Transistor, Silicon, NPN		Kepco No. 119-0118.

BOP 36–5M/10-2271/r14	C2743
BOP 36–5M/10-2271/r14	BMC
BOP 36–5M/7-372/r15	C2916
BOP 36–5M/8-1472/r16	C2926
BOP 36–5M/12–1572/r17	C3033
BOP 36–5M/5-373/r18	C3089
BOP 36–5M/12-1373/r19	C3176

KEPCO, INC. • 131-38 SANFORD AVENUE • FLUSHING, N.Y. 11352 • (212) 461-7000 • TWX # 710-582-2631 • Telex: 12-6055 • Cable: KEPCOPOWER NEWYORK

KEPCO®

INSTRUCTION MANUAL CORRECTION

Please note the following corrections to the Manual Material as indicated:

PARTS LIST AND SCHEMATIC DIAGRAM:

12.	CHANGE:	C5	Capacitor, Mica, Dipped	150 pF, 500V, 5%	Kepco #117-0675 to:
		C5	Capacitor, Ceramic, Disc.	400 pF, 3 kV, 20%	Kepco #117-0586.
13.	ADD:	C6	Capacitor, Mica, Dipped	150 pF, 500V, 5%	Kepco #117-0675.

Note: C6 has been added to assembly A1. It is connected between the base and the collector of Q4.

BOP 36–5M/8-2775/r20 C3366

KEPCO, INC. • 131-38 SANFORD AVENUE • FLUSHING, N.Y. 11352 • (212) 461-7000 • TWX # 710-582-2631 • Telex: 12-6055 • Cable: KEPCOPOWER NEWYORK

MP MASTER
MA21699